6 Identification and Screening of Technologies

The purpose of this section is to identify and screen remedial action technology types and process options that are potentially applicable for management of contaminated sediments in the Lower Fox River and Green Bay. The screening process was conducted in accordance with the EPA RI/FS Guidance (EPA, 1988). First, a list of potentially applicable technologies is prepared based on the general response actions (GRAs) anticipated for site cleanup (identified in Section 4) and on available information on various technologies and processes that either exist or are under development. Next, the list is refined by evaluating each technology for implementability, effectiveness, and relative cost. Technologies are either retained for use in developing remedial alternatives (Section 7) or are dropped from further consideration. The following provides an overview of the review process:

- The initial step involves assembling a comprehensive list of technology types and specific process options applicable to the general response actions developed in Section 4.4 that could be potentially used to manage Lower Fox River and Green Bay sediments (Section 6.1).

- Secondly, criteria are presented to screen the potential technologies based upon their implementability, effectiveness, and relative costs (Section 6.2).

- The results of the technology screening and a brief description of the primary factors that influenced the retention/elimination screening decisions are discussed. The section culminates in a list of retained process options (Section 6.3).

- A detailed description of each of the retained process options that will be carried forward into the detailed reach-specific analysis in Section 7 is provided (Section 6.4). The site-specific factors that will influence implementability or effectiveness (i.e., operational constraints) are also identified here, and will be applied in Section 7.

- Ancillary technologies (i.e., transportation of dredged sediments) that are required to implement specific management options for the Lower Fox River and Green Bay, but do not necessarily require screening, are presented (Section 6.5).

- Additional information on water quality, including protection of the water column during dredging and requirements for discharge of water from sediment handling activities, are presented (Section 6.6).

The literature sources and databases utilized to compile and evaluate a broad list of potentially applicable technology types and process options are provided in Table 6-1. In addition to these sources, available site data, and specific criteria applicable to the process options were used in the screening process.

6.1 Identification of Technologies

The first step in the FS process involves the identification of GRAs, remedial action technology types (e.g., dredging, chemical treatment, capping), and remedial action process options (e.g., horizontal auger dredge, electrochemical oxidation, sand cap). Descriptions of GRAs, technology types, and process options include:

- **General Response Actions.** These are selected to address the extent of contamination and the potential for migration of COCs for a given medium. GRAs are described in broad terms in order to encompass all possible remedial actions for achieving the remedial action objectives. By identifying appropriate response actions which apply to contaminated sediments, the list of technologies to be reviewed can be substantially reduced. The GRAs for sediment cleanup in the Lower Fox River and Green Bay are:

    - No Action,
    - Institutional Controls,
    - Monitored Natural Recovery,
    - Containment,
    - Removal,
    - *In-situ* Treatment,
    - *Ex-situ* Treatment, and
    - Disposal.

- **Technology Types.** These are general categories that describe a means for achieving the GRAs (e.g., capping, dredging, dry excavation, or chemical treatment). For example, removal is a GRA that can be achieved by excavation or dredging, while treatment is a GRA that can be achieved using biological or chemical technologies.

- **Process Options.** These are specific processes within each technology type. For example, chemical treatment, which is a technology type, includes such process options as solvent extraction and slurry oxidation. Process options are selected based on an understanding of the characteristics of the medium and technologies that are available to address the medium.

The GRAs describe, in broad terms, remedial actions theoretically capable of achieving the RAOs described in Section 4. The technologies are grouped according to the GRAs discussed in Section 4. One or more technologies and technology process options may be considered within each GRA category. Literature sources used to develop the list of potentially applicable technologies are listed in Table 6-1. A summary of the technologies and process options reviewed and retained within each GRA are listed in Table 6-2. Shaded technologies were retained for further consideration in the development of remedial alternatives for the Lower Fox River and Green Bay.

This section also presents and evaluates several ancillary technologies that, while necessary to the overall implementation of a cleanup program, are secondary to the primary functions embodied by the GRAs. For example, sediment dewatering, water treatment, suspended solids controls during dredging, and monitoring are all discussed in this section as technologies ancillary to the primary GRAs.

The list of technologies evaluated in this section is comprehensive and is supported by numerous published articles, guidance, and technology databases developed over the years for sediment remediation (Table 6-1). Many of the cited publications address technologies and cleanup approaches specific to the Lower Fox River and Green Bay or very similar sites. Finally, site-specific data from the recently completed Site N and 56/57 dredging projects on the Lower Fox River aided the evaluation and selection of dredging, sediment dewatering, and water treatment technologies. A detailed description of the technologies and process options screened in this section are listed in Table 6-3.

6.2 Screening of Technologies

The technologies listed in Table 6-2 are screened in this section of the FS to determine which are appropriate for development of sediment remedial alternatives. The screening methodology used is consistent with that presented in the EPA RI/FS Guidance (EPA, 1988). The following subsections describe the process and screening criteria used for the identified technologies.

6.2.1 Screening Criteria

The criteria used to evaluate each process option were implementability, effectiveness, and relative cost. These criteria are discussed below.

Implementability

Technical implementability refers to the technical feasibility of implementing a particular technology. Technologies that are not applicable to site characteristics or the contaminants of concern (COCs) are eliminated from further consideration. Administrative implementability considers permitting and the availability of necessary services and equipment to implement a particular technology.

Effectiveness

Determining the effectiveness of a technology involves consideration of whether the technology can contain, reduce, or eliminate the COCs and generally achieve the RAOs set forth in Section 4. Effectiveness is evaluated relative to the other technologies identified in the screening. Consideration must also be given to the many aspects of remediation that contribute to a technology's overall effectiveness including:

- How well the technology will handle the estimated areas or volumes of contaminated sediment to be remediated;
- If the RAOs will be met through implementation of the technology;
- How efficiently does the technology reduce or eliminate the COC;
- To what scale (lab-, pilot-, full-) the technology has been tested;
- Timeliness of implementation and availability; and
- How effective is the process option in protecting human health and the environment during the implementation phase of remediation.

The effectiveness evaluation focuses on PCBs as the primary COC. Metals are also considered in the screening of certain process options for treatment.

Cost

Technologies were evaluated with respect to relative capital and operations and maintenance (O&M) costs. Detailed cost estimates of remedial alternatives are provided in Section 7 of this FS Report. Costs used for this phase of the screening process are defined in terms of high, moderate, and low, rather than a specific dollar amount and are determined on the basis of engineering judgement. The cost of each process option is relative to other process options of the same technology type. Technologies are retained or eliminated based, to a lesser degree, on cost during this phase of the screening (Table 6-4).

6.2.2 Screening Process

As specified in the EPA RI/FS Guidance (EPA, 1988), a two-step screening process was used to evaluate each process option listed in Table 6-2, with the exception of technology types or process options associated with the no action GRA. The no action GRA is retained as required by NCP for use as a baseline comparison against other technologies.

In the first step, referred to as the initial screening, process options determined to be technically implementable were retained for further evaluation. Technologies that have no applicability to the COCs, are not ready for full-scale operations, or are otherwise unworkable in the context of sediment remediation were eliminated from further discussion.

In the second step, the final screening of technologies considers effectiveness and cost. In some cases where several technologies are considered similar in approach and performance, a single representative technology is retained for further evaluation. Technologies retained through the screening steps receive extensive coverage in the following subsections. During the detailed analysis of alternatives (Chapter 9 of the FS), technologies evaluated during the screening process and retained are further refined, as appropriate. Technologies and alternatives will be analyzed in detail with respect to short-term impacts associated with implementation, long-term protection of remedy, compliance with ARARs and TBCs, and reduction of toxicity, mobility, and volume of COCs.

6.3 Results of Technology Screening

The technologies screened and retained for further consideration in the development of remedial alternatives (Section 7) are shaded in Table 6-2. The following discussion briefly describes the results in advance of the detailed screening that consumes the remainder of this section.

6.3.1 No Action

No action was retained, as required by the NCP, for comparing the merits of taking no remedial action whatsoever with other technology-based remedial alternatives (Table 6-4). With a no action alternative, natural restoration is the only means by which sediment quality can improve over time. However, implementation requires no planning, decision making, maintenance, or monitoring. No action does not meet RAOs for the Lower Fox River and Green Bay.

6.3.2 Institutional Controls

Institutional controls are administrative actions (e.g., fish consumption advisories, access restrictions, dredging moratoriums) designed to prevent exposure of humans and wildlife to contaminants. Institutional controls are generally effective at limiting human exposure, but are generally ineffective at affording protection to ecological receptors where impacts are ongoing (Table 6-4). In general, institutional controls have no effect on ecological receptors. Nevertheless, institutional controls are important features of many sediment cleanup projects and are retained for further consideration in the development of remedial alternatives (EPA, 1999a).

6.3.3 Monitored Natural Recovery

Monitored natural recovery (MNR) refers to the beneficial effects of natural processes that reduce surface sediment concentrations of PCBs. These processes include biodegradation, diffusion, dilution, sorption, volatilization, chemical and biochemical stabilization of contaminants, and burial by natural deposition of cleaner sediments. The primary mechanisms for MNR in the Lower Fox River and Green Bay are desorption and dispersion in the water column (i.e., as a dissolved constituent), burial, and sediment resuspension and transport. Biodegradation is a negligible contributor to the lowering of PCB concentrations and is not a factor for mercury (see Appendix F).

MNR can be an effective alternative under the appropriate conditions. However, for the Lower Fox River it may have limited utility for the Fox River and Green Bay to be protective in a reasonable time frame because of: 1) limitations of natural dechlorination, 2) slow time trend decrease in PCB concentrations in fish and sediment, and 3) substantial fluctuations in sediment bed elevations precluding long-term burial by cleaner sediment. For example, areas of net scour and deposition have measured up to 36 cm of short-term change (annually) and 100 cm of long-term change (several years) in bed elevations (WDNR, 1999c).

MNR is retained for use in developing remedial alternatives for the Lower Fox River and Green Bay (Table 6-4). While MNR alone may not be protective of human health and the environment in heavily impacted areas, natural processes are central to evaluating the long-term performance of technology-based remedial alternatives covering the full range of cleanup action levels.

6.3.4 Containment

Various approaches to capping contaminated sediments *in situ* were evaluated (Table 6-4). Capping isolates contaminants from the overlying water column and prevents direct contact with aquatic biota. In addition, capping provides new unimpacted substrate for recolonization by benthic organisms. Capping is considered effective at isolating low-solubility and highly sorbed contaminants like PCBs, where the principal transport mechanism is sediment resuspension and deposition. Cap designs should minimize the potential for sediment resuspension under normal and extreme (storm) conditions. Cap placement as a remedial alternative assumes source control and minimal potential for recontamination from upstream sources via sediment transport.

Capping is considered both implementable and effective for containing impacted sediments in portions of the Lower Fox River and Green Bay where navigation would not be impeded. The technology is retained for use in developing remedial alternatives in Section 7. Of the various process options, conventional sand cap, armored, and composite cap designs are best suited for consideration. Specific cap materials, thicknesses, and other design parameters are selected based on site-specific conditions and design criteria. Thin-layer and enhanced caps are not appropriate for use at the site based on the time frame selected to meet the project RAOs. This is further explained in Section 6.4.4.

6.3.5 Removal

Both hydraulic and mechanical options were retained as removal options (Table 6-4). Despite recent claims that dredging is not an effective remedial alternative for PCB-impacted sediments, dredging is one of the most common remedial alternatives currently used throughout the world. There are supporting data that show that it can effectively reduce total concentrations and contaminant mass. A detailed review of local, national, and international dredging projects (summarized in Section 6.4.2 and in Appendix B) concluded that environmental dredging can feasibly remove contaminated sediments, with many projects showing reductions in surface sediment concentrations. With careful planning, application in appropriate environments, and use of engineering controls, dredging can be an effective tool to remove contaminated sediments. Hydraulic or mechanical dredging can be accomplished with minimal contaminant resuspension and transport during operations. However, removal options require water quality monitoring during and after activities and management of materials following removal.

6.3.6 *In-situ* Treatment

In-situ treatment of sediments refers to processes that fix, transform, or destroy COCs while leaving the sediments in place (i.e., without first removing the sediment). No *in-situ* technologies were retained for consideration in the development of remedial alternatives (Table 6-5). *In-situ* treatment technologies for PCBs have neither been sufficiently developed nor demonstrated in field applications.

6.3.7 *Ex-situ* Treatment

Ex-situ treatment refers to technologies that fix, transform, or destroy COCs after first removing sediment from the river or lake bottom. Three *ex-situ* treatment process options, all thermal technologies, were retained (Table 6-5). The elimination of other *ex-situ* treatment options was primarily based on media-specific characteristics (i.e., high water content of sediments), contaminant composition, and the lack of full-scale demonstrations. The retained options are incineration, high-temperature thermal desorption (HTTD) and vitrification.

6.3.8 Disposal

Disposal technologies are necessarily coupled with a removal action. Both on-site and off-site disposal technologies were retained for development of remedial alternatives (Table 6-6). The retained on-site disposal options are the level-bottom cap and confined disposal facility (CDF). These technologies involve the relocation and consolidation of dredged sediments in an engineered in-water or nearshore disposal facility. After dewatering and treatment, solids residuals may be taken to an appropriate off-site disposal facility depending upon concentration and management decisions.

6.3.9 Ancillary Technologies

Ancillary technologies and processes are essential elements of many remedial alternatives, mostly related to waste management and monitoring. Ancillaries are not subject to the same screening evaluation as remedial alternatives; however, they are discussed in this section as important considerations during selection of remedial process options (Table 6-7). Ancillary technologies and processes described in this section include:

- Dewatering,
- Wastewater treatment,
- Residuals management and disposal,
- Transportation, and
- Water quality management.

Sediment dewatering is a requirement for most disposal and treatment processes. Both passive and mechanical dewatering will be considered in the development of remedial alternatives. Passive dewatering (also referred to as gravity dewatering) involves the gravity separation of water and solids in a sedimentation basin. Mechanical dewatering involves the use of equipment such as centrifuges, hydrocyclones, belt presses, and plate-and-frame filter presses to remove moisture from the sediments. Treatment of wastewater generated during sediment dewatering may be required to meet water quality requirements before discharge back to the river or bay. At a minimum, treatment would involve gravity sedimentation and possibly filtration for solids removal.

Water quality impacts from sediment resuspension during dredging are an issue when planning a sediment removal operation. Operational controls involving modified construction practices, specialized equipment, and containment systems are effective in controlling sediment resuspension and off-site losses.

6.3.10 Monitoring

Although monitoring is not part of the technology screening process, monitoring is a key component of sediment remediation to verify project progress and success. For contaminated sediment projects, monitoring can be grouped into five categories: 1) baseline monitoring; 2) short-term monitoring during implementation; 3) verification monitoring immediately following an action; 4) operation and maintenance (O&M) monitoring of disposal sites; and 5) long-term performance monitoring to determine whether RAOs are attained. All five types of monitoring have been included in the FS costs and scope. A proposed model long-term monitoring plan has been developed to determine post-implementation effectiveness of a remedy (Appendix C).

6.4 Description and Selection of Retained Process Options

This section provides a detailed description of each of the retained process options and a review of pertinent selection criteria that influenced the screening process. The information presented in the following sections also provides the basis for development of the remedial alternatives in Section 7.

6.4.1 No Action

The GRA of no action was retained as required by the NCP for use as a baseline comparison against other technologies. The "no action" alternative requires no human intervention for cleanup. For the no action alternative, natural restoration is the only means of addressing the contaminated sediments in the Lower Fox River and Green Bay. Natural restoration may involve one or more processes that effectively reduce contaminant toxicity, mobility, or volume. These processes include biodegradation, diffusion, dilution, sorption, volatilization, and/or chemical and biochemical stabilization of contaminants. The no action alternative is unlikely to meet the RAOs, and under this alternative verification of RAOs will not be required. Selection of this process option assumes that no decision-making requirements are involved, nor is a long-term operation and maintenance plan required.

6.4.2 Institutional Controls

Institutional controls are administrative actions designed to prevent activities that could expose humans and wildlife to contaminants. The primary controls envisioned for the Lower Fox River and Green Bay are:

- Fish consumption advisories and restrictions,
- Access and use restrictions, and
- Dredging moratoriums.

Consumption advisories warn the general public of risks posed by the consumption of fish caught in affected waters. Access restrictions such as fencing or boating restrictions control human access to contaminated areas. Boating restrictions would likely include "no access" or "no anchoring" restrictions. However, enforcement of these restrictions may be difficult. Dredging moratoriums preclude sediment disturbance or removal in contaminated areas, thereby reducing short-term direct contact and sediment resuspension risks. All of these controls are potentially applicable for use in remedial alternatives.

Implementability

Implementation of institutional controls for the Lower Fox River and Green Bay requires the cooperation of the implementing agencies, local Indian tribes, and public acceptance. Enforcement of these restrictions and public acceptance may be difficult to achieve. Restrictions would also apply to local Indian tribes.

Effectiveness

Institutional controls are effective at limiting human exposures, but are generally ineffective at affording protection to ecological receptors where impacts are ongoing. Sediment resuspension and transport from the Lower Fox River to Green Bay continues under natural conditions.

Costs

Costs for institutional controls are primarily legal and administrative. In general, institutional controls are a low-cost approach to managing the risks posed by contaminated media in comparison with technology-based cleanup options that involve containment, removal, treatment, or disposal.

Screening Decision

Institutional controls are important features of many sediment cleanup projects and are retained for further consideration in the development of remedial alternatives (Section 7). The management of some remedial systems (e.g., caps, CADs) and management of any residual risk after cleanup to a specified action level above protective concentrations (SQTs) will likely require implementation of institutional controls for a period of time, until the monitored natural recovery goals and project RAOs are achieved. Institutional controls are retained as part of the monitored natural recovery alternative (Table 6-4).

6.4.3 Monitored Natural Recovery

Natural recovery refers to the effects of natural processes that lower PCB surface sediment concentrations in the Lower Fox River and Green Bay. Natural recovery involves one or more processes that effectively reduce or isolate contaminant toxicity, mobility, or volume. These processes include physical processes (sediment deposition, mixing and burial, volatilization, diffusion, dilution and transport, and/or dispersion), chemical stabilization (sorption, redox), and biological processes (biodegradation and biotransformation). Monitoring of these processes to determine their effectiveness is commonly referred to as monitored natural recovery (MNR).

Of these potential mechanisms, natural recovery of contaminated sediments primarily occurs through four processes:

1. Loss of contaminants through bacterial biodegradation.

2. Loss of contaminants through diffusion into overlying water. Diffusion and/or volatilization into the atmosphere occur as partitioning mechanisms, especially for PCB congeners with low chlorine content as they tend to be more volatile and also more soluble in water.

3. Burial of contaminated sediments through natural deposition of clean sediments.

4. Mixing of cleaner surface sediments with contaminated deeper sediments by burrowing organisms, ship scour, propeller wash, and natural water currents (i.e., dilution), or downstream dispersion/transport of impacted sediments.

As part of the FS effort, the potential for natural recovery of sediment and fish tissue quality in the Lower Fox River and Green Bay systems was assessed through three lines of inquiry related to the pathways described above. First, available research on the natural biodegradation of PCBs in aquatic systems was summarized to determine whether this mechanism can be expected to significantly influence PCB concentrations over time (located in Appendix F). Second, sediment transport and burial mechanisms were evaluated using fate and transport models, sediment core profiles, and actual changes in sediment bed elevations over time (WDNR, 1999c) (located in the Model Documentation Report). Third, existing sediment and fish tissue PCB concentration data were statistically compared in an analysis of trends over the period of time represented in the FRDB. These statistical changes in PCB-impacted sediment and fish tissue concentrations over time are discussed in the Lower Fox River Time Trends Analysis by The Mountain-Whisper-Light Statistical Consulting (located in Appendix B of the RI Report) (Mountain-Whisper-Light and RETEC, 2002). These three lines of evidence for MNR are discussed below.

Natural Dechlorination. Biodegradation of PCBs can occur by bacterial-mediated removal of chlorine atoms from the PCB biphenyl ring (dechlorination, generally anaerobic) or by breaking open the carbon rings of PCBs with low chlorine content through oxidation (aerobic degradation) (Abramowicz, 1990). The most potent PCB congeners are planar and coplanar molecules with non-ortho or mono-ortho substituted PCBs, which chemically resemble and behave like 2,3,7,8-substituted dibenzo-*p*-dioxins (PCDDs). Collectively, these compounds are referred to as planar chlorinated hydrocarbons (PCHs). However, their potencies are structure-dependent (position of the chlorine atoms) and may vary by many orders of magnitude (Walker and Peterson, 1991; Fischer *et al.*, 1998). Conceptually, the dechlorination process given sufficient time, could be considered a viable mechanism to achieve natural recovery. However, the degree of chlorine removal (magnitude) and the rate of chlorine removal (time) are germane to evaluating dechlorination and MNR as a potential remedial alternative.

Most studies of PCB-contaminated sites demonstrate that a threshold PCB concentration must exist before anaerobic dechlorination can occur (discussed in Appendix F). The threshold PCB concentration level is site-specific. At different sites, thresholds have been shown to range between 10 and 50 mg/kg. Dechlorination does occur under anaerobic conditions in nature, but only minor (10 percent or lower) reductions in total PCB concentrations are ever achieved. Little or no reductions from natural anaerobic biodegradation occurs at PCB levels below 30 ppm PCBs. Aerobic degradation of the lower chlorinated PCB congeners has been documented in controlled laboratory studies, but is poorly documented under field conditions. Aerobic degradation is not effective for highly chlorinated PCB congeners.

In the Lower Fox River, natural degradation processes have been observed (McLaughlin, 1994). The threshold concentration PCB concentration level for dechlorinating activity in the Lower Fox River is approximately 30 mg/kg (McLaughlin, 1994). For sediment deposits in the Lower Fox River with average concentrations greater than 30 mg/kg, a 10 percent reduction in PCB mass was estimated due to anaerobic processes (McLaughlin, 1994). No PCB reductions due to anaerobic process for sediments with average PCB concentrations less than 30 mg/kg can be accounted for in the Lower Fox River sediments. No aerobic PCB degradation has been documented in the Lower Fox River or Green Bay (Appendix F).

The observed degradations were attributed mostly to desorptive losses to the water column taking place during sediment transport downstream, rather than aerobic biodegradation (McLaughlin, 1994). Some anaerobic dechlorination has occurred in many deposits along with physical/chemical weathering. The differences in congener distribution between the Lower Fox River and Green Bay sediments have been attributed to chemical and physical processes such as diffusion, solubilization, and resuspension, rather than biological processes such as aerobic degradation or anaerobic dechlorination.

Thus, natural biodegradation can not be relied upon to substantively reduce PCB concentrations over time. The dechlorination of PCBs by anaerobic bacteria is not synonymous with detoxification, as congeners having more carcinogenic activity can be formed through dechlorination (Brown and Wagner, 1990). While PCB dechlorination could contribute to an overall MNR alternative for the Fox River or Green Bay, the actual mass reductions or rates cannot be reliably quantified.

Sediment Transport and Burial. Resuspension, transport, and burial of PCB-contaminated sediments are recurring mechanisms that are well documented in the Lower Fox River and Green Bay (WDNR, 1995, 1999a, 1999b, 1999c; Baird and Associates, 2000a; LimnoTech, 1999; BBL, 1999; Velleux *et al.*, 1995). Common methods for estimating the influence and extent of these processes in an aquatic environment include: estimating sedimentation rates through field-collected data, monitoring changes in bed elevations over time, monitoring surface sediment chemistry over time, monitoring surface water quality and sediment loads, and applying fate and transport models to predict sediment transport.

These mechanisms can support the natural recovery process by burial of PCB-contaminated sediments by deposition of cleaner sediments. Alternatively, PCBs in sediments can be resuspended and transported from the river into the bay, and from the bay into Lake Michigan. Burial and transport are functions of the hydraulic conditions in the system, and are reflected as scour or deposition zone. Sediment scour and deposition patterns were evaluated using primarily three lines of evidence including: 1) geochronological sediment dating from radioisotope core data (WDNR, 1995; BBL, 1999), 2) estimated scour depths from episodic storm events and model projections (Baird and Associates, 2000a), and 3) long-term changes in observed bed elevations (WDNR, 1999c). These parameters serve as important input variables to the complex fate and transport and bioaccumulation models used for the Lower Fox River (wLFRM) and Green Bay (GBTOX).

Radioisotope Vertical Profiling. Sediment fluxes and resuspension of sediments are important parameters regarding material transport and the potential for natural recovery processes over time. Gross sedimentation rate (net + resuspension) is determined by the flux of settling particulate material which settles through the water column and is deposited on the river bottom (often measured by sediment traps). Net sedimentation flux is determined by the amount of material that remains on the river bottom and is subsequently buried over time (measured by radiological dating of sediment cores). The difference between the gross and net sedimentation rates provides information on the rate at which bottom sediments are resuspended to the overlying water column by physical processes such as ice scour, water currents, or propeller wash from passing vessels where bottom sediments may be subject to transport downstream (advection) or resettling.

Changes in deposition or scour patterns within a deposit or reach are recorded in the sediment profile and can be quantified by measuring changes in levels of atmospherically-deposited radioactive isotopes (i.e., cesium-137 [Cs-137] or lead-210) known as fallout, over time. Anthropogenic inputs of Cs-137 into aquatic systems began in 1950 from atmospheric testing and radioactive releases of nuclear weapons. Peak cesium activity is generally dated at year 1963 with a second sub-peak at year 1959 (Robbins and Edgington, 1975). Cs-137 input levels declined after 1963 following the test ban between the United States and U.S.S.R. Cs-137 profiles (concentration, depth) provide a means of determining the age of a sediment layer. By examining the depth and shape of Cs-137 sediment peaks and correlating theses profiles to the source and time of Cs-137 releases to a system, the profiles can be used to determine if the sediments are being deposited and buried, or scoured and redeposited. Stable depositional zones have stratified cesium levels with discrete horizons preserved in the sediment core. Deposits that are continually disturbed and redeposited, are represented by relatively homogenous cesium levels (no observable peaks) that indicate physical vertical mixing or bioturbation is occurring. Post-depositional redistribution by physical mixing or biological processes can also account for the appearance of Cs137 at greater depths in the core than would be predicted from the inferred sedimentation rate alone (Robbins and Edgington, 1975).

Cs-137 profiles were collected as part of the 1989–1990 Green Bay Mass Balance Study to determine long-term depositional rates (Velleux and Endicott, 1994). In most of the collected cores, the measured cesium levels were consistent with the high resuspension and sediment scour events predicted in the Fox River transport models (WDNR, 1995, 2000b). Of the 24 cores collected upstream of the De Pere dam in 1989/1990, only four cores showed little evidence of sediment diffusion or mixing in the upper layers. Fifteen of the 24 cores were considered inadequate for chronology measurements because of excessive disturbance in the profile. Apparent depths of disturbance ranged from 4 cm down to 40 cm below mudline surface. Geochronological sediment cores were also collected in 1998 as part of the NRDA assessment. The long-term net sedimentation rates were calculated from two usable cores: 1.06 centimeters per year [cm/yr] above the De Pere dam and 1.11 cm/yr below the De Pere dam (BBL, 1999). These rates are consistent with the long-term sedimentation rates of 0.3 to 0.5 cm/yr estimated by USGS based on Cs-137 profiles (as reported in Fitzgerald *et al.*, 2001). The remaining cores were difficult to interpret with evidence of sudden increases in Cs-137 concentrations in surface sediments. These anomalies observed in the profiles are consistent with the 1989/1990 data and likely indicate disturbance events.

The dating method developed for the Great Lakes (Robbins and Edgington, 1975) assumed that the major source of cesium input is via direct deposition from the atmosphere and that watershed inputs of cesium are small. While this condition may be true for the Great Lakes, it is not necessarily true for the Lower Fox River. The radioactive decay process occurs at the same rate regardless of whether a particle with Cs-137 enters river sediments immediately after atmospheric fallout or whether the particle is deposited further upstream in the watershed and takes 20 years to reach the river sediments. As a result, Cs-137 can be a poor tool to "date" sediments because of its long half-life (30 years). However, Cs-137 is a useful tool for showing the vertical extent of sediment disturbance (i.e., resuspension) in the Lower Fox River and Green Bay (ranging from 4 to 40 cm below the sediment-water interface).

Beryllium-7 (Be-7) profiles were used as a tracer to determine short-term (monthly) deposition rates and to refine the predictions of sediment resuspension on a finer scale. Be-7 is produced by cosmic ray spallation of nitrogen and oxygen in the atmosphere and decays rapidly with a half-life of 53 days. In aqueous environments, beryllium strongly sorbs to suspended particles in much the same way as other isotopes and PCBs, and quickly settles to the river bottom. Be-7 was studied in two locations of the Lower Fox River during the summer and fall of 1988 (Fitzgerald *et al.*, 2001). Sediment cores were co-located with sediment trap, Cs-137 profile, and PCB profile data. Be-7 was present in the upper 6 cm, with minimal activity below 6 cm. The profiles predict quiescent periods of low deposition followed by episodic deposition/scour events. The estimated scour depth can be at least 6 cm based on these profiles. The short-term deposition rates recorded at these stations ranged from 0 to 65 cm/yr on a yearly basis (linearly projected from discrete sampling events). These rates are one to two orders of magnitude higher than the long-term predictions by Cs-137 methods. The ratio between the short-term and long-term sedimentation rates represents a measure of the non-steady-state sediment movement into or out of a river deposit over time. This ratio varies from minus 16 cm (erosional episode) to greater than 130 cm (depositional episode) and indicates the contribution of minor resuspension events to mass transport downstream and redeposition over time in these highly dynamic systems.

Sediment Deposition and Scour Models. As described in the Model Evaluation Work Plan (WDNR, 1997), the hydrodynamics and sediment transport of the river were examined as part of a series of technical reports located in the Model Documentation Report (WDNR *et al.*, 2001). Hydrodynamic models of the Lower Fox River were developed as part of Technical Memorandum 5c (HydroQual, 2000) and Technical Memorandum 5b (Baird and Associates, 2000a) to examine the structure of river currents. This information was used to estimate shear stresses in the wLFRM. Sediment transport models of the Lower Fox River were also developed as part of Technical Memorandum 5d (Baird and Associates, 2000b) and Technical Memorandum 5b (Baird and Associates, 2000a) to examine aspects of sediment transport. This information was used to help estimate the magnitude and temporal dynamics of settling and resuspension velocities in the wLFRM.

Key findings of the technical memoranda related to sediment deposition and scour are discussed below and state that for any given resuspension event, the particle resuspension flux can be described as a function of the shear stress at the sediment-water interface, which can in turn be approximated as a function of flow. It is generally accepted that flow velocities increase with increasing surface water discharges; and that as flow rates increase, the scour depth and quantity of suspended solids in the water column increase. During a simulated high 100-year flow event of 24,000 cfs (685 m^3/s, surface shear stress of 4 to 24 dynes per square centimeter) below the De Pere dam, the predicted bed elevation change varied from 1 to 5 cm depth in the Lower Fox River (Baird and Associates, 2000a). Differences in flow rates at more regular intervals (i.e., 2- and 5-year intervals) are relatively small because the multiple dams and reservoirs throughout the river tend to smooth out the peak flow events.

An additional dimension of the deposition/scour analysis is the spatial scale of the hydrodynamic models applied to the Lower Fox River and Green Bay. All of the models applied to the Fox River are fairly coarse-scale evaluations of average changes in bed elevation over large areas of the riverbed (50 acres). The extrapolation of these coarse-scale model results are likely underpredictive with respect to bed sediment mixing and off-site transport. Finer-scale bed changes within a given model unit that occur from smaller-scale bedform dynamics will not be resolved by the model and will therefore under-predict localized scour and contaminant redistribution. Although these modeled events predict a maximum erosion depth (i.e., elevation loss) per event, the technical memoranda summarize that higher erosional events may occur, shear stresses are likely higher than predicted, and that the models cannot predict the range and magnitude of bed elevation changes observed in USGS monitoring data (discussed below).

Bed Elevation Changes. The magnitude of bed elevation changes measured in the De Pere to Green Bay Reach of the Lower Fox River (WDNR, 1999c) were significantly higher than the model-predicted scour depths during short-term storm events. The elevation change for short-term cycles (sub-annual) in the De Pere to Green Bay Reach ranged between 28 and 36 cm for both losses and gains. The elevation change measured over many years (a 25-year period) ranged between a 45-cm increase (net deposition) and 100-cm decrease (net scour). A maximum point change in bed elevation of 200 cm has been observed over a 7-year period (WDNR, 1999c). Flow events and their ability to erode bottom sediments are dependent not only upon the measured stream flow velocities, but also upon the cross-sectional depth of water, lake levels, operation of dams during flood conditions, and wind conditions that produce seiche events near the mouth of the Fox River.

In summary, monitored natural recovery may be appropriate in quiescent areas with net sediment deposition and little erosion potential. In these areas, sediment burial with non-impacted sediments may be possible. Based on radioisotope profiles (Fitzgerald *et al.*, 2001), short-term episodic storm events can expect scouring up to 6-cm depths and greater. In river channel areas with increased stream flow velocities and shear stresses encountered during moderate storm events (a 100-year storm event is not required) resuspension and downstream transport of surface sediment is likely. Additionally, long-term trends in observed bed elevation changes show that significant resuspension and redeposition (up to 100 and 45 cm, respectively) can occur over a period of many years (observed for 25 years) with little spatial or temporal continuity. Finally, these observed trends are based upon the existing hydraulic conditions that are in large part governed by the system of dams on the river. Any MNR alternative considered for a river reach would implicitly require maintenance of the dams, or explicitly require consideration of the effects of dam removal.

Time Trends Analysis. PCB concentrations in sediments and fish tissue can be reliable measures of changing conditions since PCBs tend to persist in sediments and bioaccumulate in fish and other animals for long periods of time. The time trends analysis summarized in Section 2.6 presented evidence that concentrations of PCBs in fish tissue and surface sediments have generally declined following the elimination of PCB point source discharges. Statistically significant breakpoints in the decline for most of the fish species examined suggest that the decline has slowed down or, in some cases, that tissue concentrations of PCBs have actually increased.

Data on PCBs in surface sediment samples suggest that PCB concentrations have generally declined over time. Trends in concentrations of PCBs in subsurface sediments are mixed; some deposits show declining trends, while others show trends either close to zero or not significantly different from zero, and yet others show increasing trends. The time trends appear to be quite changeable and confidence intervals for rates are quite wide so that it is not possible to project PCB concentrations into the future for fish or sediment with much confidence.

The time trends analysis was a purely statistical exercise that offered no insight into the mechanism(s) responsible for declining sediment PCB concentrations. The primary attenuating mechanisms for PCBs in the Lower Fox River and Green Bay are sediment resuspension and transport, followed to a lesser degree by desorption and dispersion in the water column (Section 2.5). Biodegradation, resulting from the actions of naturally occurring aerobic and anaerobic microorganisms in the sediments, is believed to be a minor contributor to changes in PCB concentrations.

In summary, much of the Lower Fox River system undergoes both erosional and depositional events, with areas of net deposition, creating areas known as "sediment deposits." However, in net depositional areas where settling exceeds erosion, erosion can still occur. Locating areas of long-term net sediment deposition that are not susceptible to erosional scour events need to be addressed prior to implementing a monitored natural recovery alternative. Transport modeling and bathymetry results indicated that significant erosion is confined to mostly the deeper, mid-channel river sediments (during periods of high flow), while the nearshore sediments are not eroded (Velleux *et al.*, 1995). Both the Be-7 and the Cs-137 data suggest that there are some areas within the Lower Fox River that may be net depositional (i.e., over long periods gross deposition exceeds gross erosion), but that on the aggregate, most deposits are subject to scour and resuspension.

Implementability

EPA has issued guidance for implementing MNR cleanup remedies at sites involving soil or groundwater contamination (EPA, 1999b). No specific guidance is available for implementing MNR remedies at sediment sites. However, EPA expects that similar natural attenuation considerations for upland sites also apply to sediments (EPA, 1998a).

MNR is an implementable remedy from a technical standpoint, as the means are available for monitoring environmental quality and modeling the rate of natural restoration. In high-energy environments, sediment scour and transport is likely to dominate sediment recovery processes, while in low-energy environments, bioturbation is likely to dominate contaminant movement in the upper layer of sediments. Physical processes such as net burial and isolation of impacted sediments is also likely to dominate the recovery process in low-energy environments. An MNR remedy would require long-term monitoring of Lower Fox River and Green Bay fish tissue, water quality, and sediment quality. This data could be used in conjunction with fate and transport models to determine the rate and extent of natural restoration actually occurring.

Effectiveness

MNR alone would likely be insufficient to meet project RAOs in the short- or long-term in many portions of the river and bay. Natural recovery may be sufficient in localized nearshore quiescent areas with only minor contamination and accumulating sediments. In areas of the river and bay with higher levels of contaminants and higher potential for scour events, MNR may become an integral component of an active remedy involving some degree of containment or removal. For example, MNR may be effective at reducing residual COC concentrations to acceptable levels over an extended period once the more contaminated sediments are removed. Monitored natural recovery may be an appropriate remedial alternative when:

- Large volumes of contaminated sediment have marginal levels of contamination;
- The area is a low-energy, depositional environment;
- Dredging for navigational needs are not required;
- Site restrictions and institutional controls are acceptable;
- Review of existing data suggest that the system is naturally attenuating and will continue to do so within an acceptable time frame; and
- The cost for an active remedy disproportionately outweighs the risk reduction benefit.

Monitored natural recovery has been selected as the primary remedial alternative at two sediment sites in the United States: 1) James River in Hopewell, Virginia; and 2) the Sangamo Weston/Twelve Mile Creek/Lake Hartwell Superfund site in South Carolina (described in Appendix B). At the Sangamo Weston site, for example, the selected remedy focused on extensive source control of PCB-impacted sediments in Twelve Mile Creek, and monitoring the recovery of sediment and biota in the quiescent, depositional waters of Lake Hartwell over time. Annual monitoring since 1994 has shown measurable decreases in surface sediment concentrations of PCBs. Burial by clean sediment is thought to be the dominant recovery process with measurable contributions from periodic releases by upstream dams. Sediment accumulation rates in Lake Hartwell, estimated from 10 samples collected during 2000 by radioisotope profiling methods, ranged from 0.66 to 19 cm/year. The sediment cores also showed that the PCB congener composition became increasingly dominated by lower chlorinated congeners with sediment depth and corresponding age, resulting in a relative accumulation of ortho-chlorinated congeners and losses of meta- and para-chlorinated congeners. This preliminary evaluation suggests that partial dechlorination in deeper sediments and dissolution/volatilization in surface sediments may also be contributing to the PCB degradation mechanisms at the site. It is possible that a concentration of ortho-substituted congeners at a given site represents the lower limit to the extent of dechlorination achievable at that site (http://www.clu-in.org/Products/NEWSLTRS/TTREND/tt0301.htm). Other case studies regarding the observed extent of biological degradation processes are described in Appendix F.

Costs

MNR is a generally a low-cost technology because no active sediment remediation occurs that involves containment, removal, or treatment. However, monitoring costs may be significant, extending into the millions of dollars, depending on the term and magnitude of the monitoring program.

Long-term monitoring costs vary widely depending upon the project expectations, media of concern, and residual risks. For the purposes of this FS, sampling costs for sediment, water, bird, fish, and invertebrate tissue are approximately $600,000 per sampling year (every fifth year), with a total present worth monitoring cost of $11.8 million over 40 years for each reach/zone (Appendix C). The *Long-term Monitoring Plan* (LTMP) located in Appendix C will likely be refined and finalized after the remedy has been selected. Elements of the LTMP may differ between locations with residual risk with areas meeting the most protective SQT criteria.

Screening Decision

MNR is retained for use in developing remedial alternatives for the Lower Fox River and Green Bay (Table 6-4). As discussed above, MNR alone is unlikely to be an effective remedial approach in heavily-impacted areas of the site because of the anticipated time required to reach the project RAOs. In these areas where PCB concentrations exceed the apparent dechlorination threshold of 30 mg/kg described above, dechlorination of the PCB molecule is not a viable process. However, MNR alone may be a viable remedial alternative in areas where the PCB concentrations are moderate, impacted sediments are widely dispersed, and the inventory of PCB mass is relatively low due to historical natural dispersion or burial activities. Natural recovery processes are also critical components to the evaluation of cleanup alternatives over a range of cleanup action levels as described in Section 5.

6.4.4 Containment

In-situ capping is the containment and isolation of contaminated sediments by the placement of clean materials over the existing substrate. This alternative does not require removal of sediment; clean sediments are placed over old sediments as a barrier, isolating contaminants within the substrate. Capping of subaqueous contaminated sediments has become an accepted engineering option for managing dredged materials of *in-situ* remediation (NRC, 1997; EPA, 1991, 1994a; Palermo *et al.*, 1998). There are multiple references that discuss physical considerations, design, and monitoring requirements for capping. The following references were used in this FS Report to assess the applicability of containment technologies:

- *Review of Removal, Containment and Treatment Technologies for Remediation of Contaminated Sediment in the Great Lakes* (Averett *et al.*, 1990);

- *Design Requirements for Capping* (Palermo, 1991);

- *Guidance for In Situ Subaqueous Capping of Contaminated Sediments* (Palermo *et al.*, 1998);

- *Placement Techniques for Capping Contaminated Sediments* (Palermo, 1994);

- *Washington State Department of Ecology 1990 Standards for Confined Disposal of Contaminated Sediments Development Document* (Ecology, 1990);

- *Equipment and Placement Techniques for Capping* (USACE, 1991);

- *Monitoring Considerations for Capping* (USACE, 1992);

- *Subaqueous Capping of Contaminated Sediments: Annotated Bibliography* (Zeeman, *et al.*, 1992); and

- *Design Considerations for Capping/Armoring of Contaminated Sediments In-Place* (Maynord and Oswalt, 1993a).

The last two references describe capping design and structural considerations for capping in a riverine environment in the Great Lakes.

Description of Containment Process Options

Caps may be grouped into three general categories: conventional sand, armored, and composite. Conventional capping includes sand and clay caps. Other miscellaneous capping techniques include thin-layer capping and enhanced capping.

Conventional Capping. Conventional caps involve the placement of sand or other suitable cover material (i.e., clay) over the top of contaminated sediments. Material selection and cap thickness are determined based on consideration of contaminant properties and local hydraulic conditions. Sandy soils and sediments are typically preferred as cap materials over fine-grained materials. The latter are more difficult to place evenly, cause a great deal of turbidity during placement, and are more erosive. A cap thickness of 30 to 50 cm is considered sufficient to chemically isolate PCBs and metals (Palermo, 1994).

Capping operations can disturb and displace loose fine-grained bottom sediment, resulting in resuspension losses and mixing of contaminants into the clean capping layer. Physical characteristics, such as solids content, plasticity, shear strength, consolidation, and grain size distribution affect the displacement of sediment. The sediment characteristics will often form the basis for determining the suitability of capping materials and placement options (Palermo, 1991).

A variety of methods are available for constructing conventional caps in riverine environments:

- Hydraulic pipeline delivery of a sand slurry through a floating spreader box or submerged diffuser;

- Physical dispersion of barged capping materials by dozing, clamming, or washing of material that settles through the water column;

- Distribution by controlled discharge from hopper barges;

- Mechanically-fed tremie to the river bottom; and

- High-pressure spraying of a hydraulic sediment-water slurry across the water surface.

The method used to place the cap material must be capable of achieving even placement of material over the target area while limiting the resuspension and loss of contaminated sediment into the water column or the emerging cap layer. Even placement and limited resuspension of contaminated sediment are generally achieved when the capping materials are dispersed and allowed to settle through the water column. The dumping of large, dense masses of capping material (e.g., pushing sands off a barge) or methods that lead to density-driven hydraulic flow should be avoided.

A summary of conventional capping projects in North America is provided in Appendix D.

Armored Capping. Armored caps are similar to conventional caps with the exception that the primary capping material (e.g., sand) is covered with stone or other suitable riprap (the armor) to add physical stability in erosive environments. Armored caps are commonly used in environments where high water velocities (i.e., flood flow, propeller wash) threaten the cap integrity. Examples of armored caps from Sheboygan Falls, Wisconsin and Manistique Harbor, Michigan are illustrated on Figure 6-1. However, the Manistique cap was never implemented and is solely based upon preliminary design drawings.

The conventional portion of the cap is placed using one of the previously described methods. Armoring materials (quarried rock or concrete riprap) are then barged to the site and placed using conventional equipment (excavators, cranes). Methods for determining the appropriate armor stone grade and thickness can be found in the *Assessment and Remediation of Contaminated Sediments (ARCS) Sediment Capping Study Final Report* (Maynord and Oswalt, 1993b).

Composite Capping. A composite cap generally involves placement of a geotextile or flexible membrane liner directly over the contaminated sediments. Permeable or impermeable liners may be considered, depending upon the migration potential of the chemical(s) of concern, and the potential for methane buildup under the liner in highly organic sediments. The liner is then armored with stone or riprap to ensure the physical integrity of the cap. Composite caps may also include a sand or activated carbon layer to capture any potential diffusive or advective migration of the underlying contaminants. For non-mobile contaminants, such as PCBs, the composite cap would likely only require a liner and armoring. A composite cap was placed at the Manistique River/Harbor site as a temporary containment measure (Figure 6-1).

Miscellaneous Capping Techniques. Additional capping approaches, besides those described above, have received attention in the capping literature including thin-layer capping, Aquiblock™, and Claymax™. Thin-layer capping involves the placement of a thin (1- to 3-inch) layer of clean sediments, that is subsequently mixed with the underlying contaminated sediments, to achieve acceptable COC concentrations and/or enhance the natural attenuation process. Mixing occurs naturally as a result of benthic organism activity (bioturbation). This approach is best suited to situations involving contaminants that naturally attenuate over time. However, PCBs do not naturally attenuate to any significant degree and, therefore, thin-layer capping would simply dilute surface sediment PCBs. Thin-layer capping would simply increase the volume of contaminated material albeit at reduced average concentrations. Aquiblock™ technology was used on the Ottawa River, Ohio as a pilot test, and Claymax™ technology was used on floodplain soils for Hudson River sediments.

Enhanced capping involves the incorporation of materials such as activated carbon, iron filings, imbiber beads, or other agents into the base capping material (e.g., sand) to enhance adsorption or *in-situ* chemical reaction. This approach is intended for circumstances in which contaminants are mobile and are expected to migrate through the cap as dissolved constituents in the pore water. These conditions do not exist at the site as PCBs are highly adsorbed to sediments and have a very low potential for migrating in sediment pore water.

Screening Criteria for Cap Selection

The criteria used for selection of a capping alternative are: presence of sediments with PCB concentrations of 50 ppm or greater (referred to as TSCA-level sediments, where the TSCA level is 50 ppm), site bathymetry, and current speed (median and 100-year flood). The latter two criteria are based upon general design guidance that caps should only be placed in a low-energy environment with little potential for erosion or disturbance of the cap (Palermo *et al.*, 1998).

- **Contaminant Concentration.** *Capping is not considered for sediments where total PCB concentrations exceed the 50 ppm TSCA level, unless the alternative involves removal of all TSCA-level material prior to capping.* Areas with sediment PCB concentrations exceeding the TSCA level of 50 ppm are unlikely to receive regulatory approval for capping. EPA has determined that capping of PCB-contaminated sediments is an action to contain and confine PCBs, though concentrations of 50 ppm or greater may not be approved by EPA (EPA Region 5 letter dated July 15, 1994, provided in Appendix E).

- **Site Bathymetry.** *The final constructed water depth shall be no less than 3 feet*. Site-specific water depth must be considered in selecting a cap as an option. To maintain physical integrity, the cap surface must be sufficiently below the water surface to minimize the potential for ice damage, ice flow scour, wind-induced currents or waves, and vessel draft. Commercial and recreational boating use of an area must also be considered to ensure both adequate draft clearance, as well as the potential damage from anchors or propeller wash. Since the maximum vessel draft, depth of ice scour, and propeller wash depth for recreational boats operating along the Fox River is approximately 2 feet, a minimum water depth of 3 feet should be maintained.

- **Currents.** *Capping is considered an alternative for a given river reach where the average current speed is less than 0.15 feet/second (ft/s), and the maximum (100-year flood) current speed is no greater than 0.7 ft/s.* Currents are important to consider because of their potential to cause scour and physical erosion of the cap. Consideration of currents should include both normal flow, flood events, and dramatic water fluctuation that may result from dam failure or dam drawdown. For a conventional sand cap, the site conditions should generally be non-dispersive in a relatively low-energy environment with low bottom current velocity. In addition, commercial boat-induced currents (propeller wash) should be considered. In the Lower Fox River, flood-flow velocities in the central river channels are expected to be the dominant potential erosional force within the Little Lake Butte des Morts Reach and the Little Rapids to De Pere Reach. Below the De Pere dam, navigation-induced water movement from the wake of a large boat or propeller wash should be considered in any potential capping scenario. Detailed evaluation methods for quantifying erosional potential are given in Palermo *et al.* (1998).

Additional guidance that is applied in this FS concerning the placement of a cap in the Lower Fox River includes the following:

- **Navigation Channels.** Capping is not selected as an alternative within the designated federal navigation channel below the De Pere dam, since periodic maintenance dredging may be required to support vessel draft of large commercial traffic (commercial vessels are limited to below the De Pere dam). While a constructed water depth of greater than 25 feet is sufficient clearance for most vessels, cap placement within the channel would require substantial armoring to protect against erosion by propeller wash, and would result in permanent deed restrictions prohibiting maintenance dredging and/or navigational improvements. In addition, any changes to the navigational channels would require congressional authorization to modify the federally-authorized depth of the navigation channel, assuming a cap placement would limit maintenance to the designated depth.

- **Bottom Sediment Characteristics.** As discussed earlier in this section, specific sediment characteristics will often form the basis for determining the suitability of capping materials and placement options.

- **Capping Materials.** For thin-layer capping, use of clean uniform granular materials (sands, fine gravels) enhances reliable application of the design layer thickness. Clumpy materials (cohesive silts/clays) and/or variable size gravels are more difficult to place evenly, and may only be placed by mechanical means.

- **Placement Method.** Both mechanical and hydraulic methods have been used for cap placement. Mechanical placement of capping material allows for greater placement accuracy while minimizing downstream turbidity. Restrictions to the mechanical application of capping material are related to the draft depths of the material barges, which are generally 8 to 10 feet. Hydraulic placement is not restricted by water depth, and has the advantage of minimizing the resuspension of contaminated sediment losses described above. Conversely, the placement activity itself will result in a temporary increase in downstream suspended solids due to the cap material.

- **Impact to Riverine Habitat and Future Use.** The impact to riverine habitat and long-term use of the site must be considered in selection of a capping option. Creation of a cap will result in change of the site depth, which can significantly change the quality of the aquatic habitat. Conventional, armored, or composite caps result in significant change in substrate type, which can influence the functioning of the benthic community and food chain interactions.

- **Institutional Notifications/Monitoring.** All capping options result in permanent restrictions to future site use, as well as long-term monitoring and maintenance of the cap.

Implementability

Conventional sand caps and armored sand caps have been successfully placed over contaminated sediments in many in-water lakes (Soda Lake, Wyoming; Hamilton Harbour, Canada) and marine environments (Minamata Bay, Japan; New York Mud Dump; Eagle Harbor, Washington) (Palermo *et al.*, 1998). Other Puget Sound projects that have involved in-place capping of contaminated sediments included Simpson Tacoma Kraft (Commencement Bay), Denny Way (Elliott Bay), and Seattle Ferry Terminal (Elliott Bay). A few caps have been placed in riverine environments, but the number of projects is relatively few (Duwamish River, Washington) when compared to other systems. See Appendix D for a list of capping projects placed over contaminated sediments (metals, PAHs, PCBs). Average cap thickness has ranged from 1 to 5 feet thick and post-cap sediment cores show effective isolation of underlying material in most cases. Geosynthetic liner caps were used at the Minamata Bay, Japan, and Soer Fjord, Norway sites.

Placement of capping material can be accomplished by open-water surface discharge using a split-bottom hopper barge or subsurface discharge using a tremie pipe for more accurate placement. The site considerations listed above (i.e., bathymetry, surface water flow, substrate type) are all important design requirements for successful placement of a containment cap. Long-term chemical stability, erosion, and consolidation potentials should also be examined prior to placement.

In-situ sand capping may not be feasible if the bottom sediment is extremely soft where the sediment cannot support a cap, or if water flow conditions would impede accurate placement of sand material.

Effectiveness

Capping is meant to isolate contaminants from the overlying water column and prevents direct contact with aquatic biota. In addition, capping provides new clean substrate for recolonization by benthic organisms. Capping is considered very effective for low-solubility and highly sorbed contaminants, like PCBs, where the principal transport mechanism is sediment resuspension and deposition. Cap designs must preclude the potential for sediment resuspension under normal and extreme (storm) conditions.

The impact to riverine habitat and long-term use of the site must be considered in selection of a capping option. Impacts include changes to the site depth, navigational and recreational uses, substrate type, and benthic community and food chain interactions. Creation of a cap will result in permanent restrictions and site access limitations in order to ensure adequate protection.

Conventional and armored caps may be effective for containing PCBs and mercury. Use of geotextiles (composite cap) may be an effective substitute for sand or clean sediment, but would likely require some form of armoring. Enhancing the cap medium with carbon or some other reactive agent is not necessary to prevent chemical migration of PCBs and mercury.

Capping Costs

Costs for capping are moderate with respect to more intensive approaches involving removal, treatment, or disposal. Total cap costs typically range from $30 to $50 per square meter ($300,000 to $500,000 per hectare), depending on cap construction and placement technique (EPA, 1994a).

Screening Decision

Capping is considered both implementable and effective for containing impacted sediments in portions of the Lower Fox River and Green Bay. The technology is retained for use in development of remedial alternatives in Section 7. Of the various process options, conventional, armored, and composite cap designs are best suited for consideration. Specific cap materials, thicknesses, and other design parameters are selected based on site-specific conditions and design criteria. Armored caps will be retained as the representative process option for in-place containment actions.

6.4.5 Removal

Removal refers to excavation or dredging of sediments. The discussion of removal process options herein integrates site knowledge, practical dredging experience, dredging sediment case studies, and demonstrated successful application under similar conditions found throughout the Lower Fox River. Wherever possible, Great Lakes practical experience was utilized to assess the applicability of a specific removal technology. Pilot demonstration dredging projects at Deposit N (in the Appleton to Little Rapids Reach) and SMU 56/57 (in the De Pere to Green Bay Reach) provide site-specific information on the implementability and effectiveness of dredging in the Lower Fox River.

The usefulness of dredging as a viable remedial technology is described, in depth, in the *Sediment Technologies Memorandum* located in Appendix B. This review paper provides a detailed review and summary of many large-scale environmental dredging projects. The major findings of this review and results from the two Lower Fox River demonstration projects (detailed in Appendix B) were used to assess the viability of dredging as a remedial technology. A few guidance documents also provided practical implementation information for sediment remediation projects in the Great Lakes region:

- *Assessment and Remediation of Contaminated Sediments (ARCS) Program, Remediation Guidance Document* (EPA, 1994a);

- *Review of Removal, Containment and Treatment Technologies for Remediation of Contaminated Sediment in the Great Lakes* (Averett *et al.*, 1990);

- *Innovations in Dredging Technology: Equipment, Operations, and Management*, USACE DOER Program (McLellan and Hopman, 2000);

- *Dredging, Remediation, and Containment of Contaminated Sediments* (Demars *et al.*, 1995); and

- *Guidance for Subaqueous Dredged Material Capping*, USACE (Palermo *et al.*, 1998).

Description of Removal Process Options

For the purposes of this FS, dredging is defined as the removal of sediment in the presence of overlying water (utilizing mechanical or hydraulic removal techniques). Wet excavation is defined as the in-water removal of sediment using typical earth moving equipment such as excavators and backhoes. Dry excavation is defined as the berming or rerouting of overlying water to create dewatered conditions accessible by upland earth moving equipment. Three categories of removal technologies are commonly considered for sediment removal in "wet" conditions with overlying water:

- Mechanical dredging,
- Excavators, and
- Hydraulic dredging.

All three of these technologies were retained for consideration during the development of remedial alternatives and are described in more detail below.

Mechanical Dredging. A mechanical dredge consists of a suspended or manipulated bucket that "bites" the sediment and raises it to the surface (Figure 6-2). The sediment is deposited on a haul barge, as illustrated on Figure 6-3, or other vessel for transport to disposal sites. A mechanical dredge and haul operation is currently used for routine maintenance dredging of the federal navigational channel in the Lower Fox River and Green Bay.

Under suitable conditions, mechanical dredges are capable of removing sediment at near *in-situ* densities, with almost no additional water entrainment in the dredged mass and little free water in the filled bucket. A low water content is important if dewatering is required for ultimate sediment treatment or upland disposal.

Clamshell buckets (open and closed), dragline buckets, dipper dredges, and bucket ladder dredges are all examples of mechanical dredges. Dragline, dipper, and bucket ladder dredges are open-mouthed conveyances and are generally considered unsuitable where sediment resuspension must be minimized to limit the spread of sediment contaminants (EPA, 1994a). Consequently, dragline, dipper, and bucket ladder techniques are not considered further in this FS Report.

The clamshell bucket dredge, or grab-dredge, is widely used in the United States and throughout the world. It typically consists of a barge-mounted floating crane maneuvering a cable-suspended dredging bucket. The crane barge is held in place for stable accurate digging by deployable vertical spuds imbedded into the sediment. The operator lowers the clamshell bucket to the bottom, allowing it to sink into the sediment on contact. The bucket is closed, then lifted through the water column to the surface, swung to the side, and emptied into a waiting haul barge. When loaded, the haul barge is moved to shore where a second clamshell unloads the barge for re-handling and/or transport to treatment or disposal facilities. Clamshell dredges can work in depths over 100 feet, and using advanced positioning equipment (e.g., differential global positioning systems [DGPS]), dredging accuracy is on the order of ± 1 foot horizontally and ± 0.5 foot vertically. Clamshell buckets are designated by their digging capacity when full and range in size from less than 1 cy to more than 50 cy.

A conventional clamshell bucket may not be appropriate for removal of contaminated sediments from some areas of the Lower Fox River. Conventional buckets have a rounded cut that leaves a somewhat cratered sediment surface on the bottom. This irregular bottom surface results in the need to over-dredge to achieve a minimum depth of cut, and can also encourage dense resuspended sediment losses to settle in the craters. Furthermore, the conventional open clamshell bucket is prone to sediment losses over the top during retrieval. Recent innovations in bucket design have reduced the spill and sediment resuspension potential by enclosing the bucket top (Figure 6-2). Also, buckets can be fitted with tongue-in-groove rubber seals to limit sediment losses through the bottom and sides.

A recent alternative bucket demonstrated in several tests and prototype sediment remediation projects is the proprietary Cable Arm® bucket (Figure 6-2). This bucket offers the advantages of a large footprint, a level cut, the capability to remove even layers of sediment, and under careful operating conditions, reduce resuspension losses to the water column as shown on Figure 6-3. The Cable Arm®

bucket has been successfully demonstrated for contaminated sediment removal at a number of sites in the Great Lakes (Cleland, 1997; SEDTEC, 1997), and was used in a removal action in the summer of 1997 at a creosote-contaminated site in Thunder Bay, Ontario.

Production rates for clamshell dredging are highly project-specific. For navigation dredging, a 5-cy bucket might deliver more than 200 cubic yards per hour (cy/hr). This same bucket might only produce 20 to 30 cy/hr in controlled sediment remediation work so as to achieve a thorough removal, limit resuspension, minimize water content, comply with water quality constraints, and limit over-dredging. The presence of large debris requiring separation and re-handling will also slow dredging progress.

Excavators. This is a subset of mechanical dredges which includes barge-mounted backhoe and/or excavators, both of which have limited reach capability. Excavators can also be used for dry excavation where the overlying water is removed. Special closing buckets are available to reduce sediment losses and entrained water during excavation. Use of conventional excavating equipment is generally restricted to removal of contaminated sediment and debris in shallow water environments or dry excavations (areas that are bermed, then dewatered for access by land-based equipment). Dewatering of an area for dry dredging involves hydraulic isolation/removal of surface water using: 1) earthen dams, 2) sheet piling, or 3) rerouting the water body using dams. Although normally land-based, excavators can be positioned on floating equipment (e.g., spud-barge) for dredging in shallow environments.

A conventional excavator bucket is open at the top which may contribute to sediment resuspension and loss during dredging, although careful operation can minimize losses. Various improved excavating buckets have been developed which essentially enclose the dredged materials within the bucket prior to lifting through the water column. A special enclosed digging bucket was successfully used on the large excavator "Bonacavor" (C. F. Bean Corp.) for remediation of highly contaminated sediment in Slidell, Louisiana (NRC, 1997). Dredged material removed by backhoe exhibits much the same characteristics as for clamshell dredging, including near *in-situ* densities and limited free water.

Hydraulic Dredges. Hydraulic dredges remove and transport dredged materials as a pumped sediment-water slurry. The sediment is dislodged by mechanical agitation, cutterhead, augers, or by high-pressure water or air jets (Figure 6-4). In very soft sediment, it may be possible to remove surface sediment by straight suction and/or by forcing the intake into the sediment without dislodgement. The loosened slurry is essentially then "vacuumed" into the intake pipe by the dredge pump and transported over long distances through the dredge discharge pipeline. Figure 6-5 provides an illustration of a hydraulic dredge with a pipeline to an upland gravity dewatering cell, and Figure 6-6 shows a conceptual layout of a gravity dewatering cell.

Common hydraulic dredges include the conventional round cutterhead, horizontal auger cutterhead, open suction, dust pan, and hopper dredges. The conventional cutterhead and horizontal auger dredges are illustrated on Figure 6-4. Specialty hydraulic dredges are available that limit resuspension losses at the dredge head and increase the solids content of the dredged slurry. These latter include the auger-, cleanup-, and refresher-type dredges. Hydraulic dredges are rated by discharge pipe diameter, and those available in the Great Lakes range from smaller portable machines in the 6- to 16-inch category, to large 24- to 30-inch dredges. The most suitable and available hydraulic dredges for the Lower Fox River project are the open suction, cutterhead, and auger types. These are discussed below.

Suction dredges are open-ended hydraulic pipes that are limited to dredging soft, free-flowing, and unconsolidated material. As suction dredges are not equipped with any kind of cutting devices, they produce very little resuspension of solids during dredging. However, the presence of trash, logs, or other debris in the dredged material will clog the suction and greatly reduce the effectiveness of the dredge (Averett *et al.*, 1990).

The hydraulic pipeline cutterhead suction dredge is commonly used, with approximately 300 operating nationwide. The cutterhead is considered efficient and versatile (Averett *et al.*, 1990). It is similar to the open suction dredge, but is equipped with a rotating cutter surrounding the intake of the suction pipe. The combination of mechanical cutting action and hydraulic suction allows the dredge to work effectively in a wide range of sediment environments. Resuspension of sediments during cutterhead excavation is strongly dependent on operational parameters such as thickness of cut, rate of swing, and cutter rotation rate. Proper balance of operational parameters can result in suspended sediment concentrations as low as 10 mg/L in the vicinity of the cutterhead. More commonly, cutterheads produce suspended solids in the 50 to 150 mg/L range.

The horizontal auger dredge is a relatively small portable hydraulic dredge designed for projects where a small (50 to 120 cy/hr) discharge rate is desired. In contrast to a cutterhead, the auger dredge is equipped with horizontal cutter knives and a spiral auger that cuts the material and moves it laterally toward the center of the auger, where it is picked up by the suction. There are more than 500 horizontal auger dredges in operation. A specialized horizontal auger dredge has been used at the Manistique Harbor Superfund site.

The Toyo pump is a proprietary electrically-driven compact submerged pump assembly that is maneuvered into position using a derrick barge. This pump is capable of high solids production in uncohesive sediment and can be equipped with a rotating cutter or jet-ring to loosen sediment. This is a lower head pump that typically discharges through 6- to 12-inch-diameter pipes and may require a booster pump for long pipeline distances. Typically, slurry discharges are at a density of approximately one-third the *in-situ* density.

The Pneuma® pump is a proprietary pump developed in Italy that uses compressed air and vacuum system to dislodge sediments through a pipeline. It may be suspended from a crane or barge and generally operates like a cutterhead dredge. It was used at the Collingwood, Ontario demonstration dredging project (EPA, 1994a).

An important consideration in hydraulic dredging is the quantity of water needing treatment after dewatering from the dredge slurry. The greater the solids content of the dredge slurry, the better the relative removal efficiency and the less water needing treatment. Typical solids content (wet) for dredge slurry ranges between 5 and 8 percent w/w, but can be less than 5 percent. For the Lower Fox River demonstration projects, the average percent solids was 5 percent w/w with a maximum solids content of about 12 percent w/w. Factors influencing the solids content include dredge type, nature of sediment, condition of equipment, and operator skill and experience.

Screening Criteria for Dredging

Selection of appropriate dredging technologies and their potential effectiveness is dependent upon more than one variable. It is a formulaic effort considering multiple variables ranging from water depth to disposal sites. Significant operating parameters and constraints considered in selecting and applying the appropriate dredging equipment for the Lower Fox River and Green Bay include:

- **Operating Depths.** *Consider hydraulic dredging in areas with shallow water depths less than 8 feet.* Hydraulic dredging is selected for alternatives in areas where the depth of water is less than 8 feet. Small hydraulic dredges have been successfully utilized in river depths as shallow as 3 feet, whereas mechanical dredges are typically limited to minimum water depths of 8 to 10 feet, principally by the draw of the transport barges required to move the dredged materials to shore. Where water depths are greater than 8 feet, both hydraulic and mechanical dredging options are considered. The method carried forward in the FS depends upon sediment removal volumes (i.e., small hotspot removals of TSCA sediments), upland space capacity for dewatering, and disposal. In shallow areas, dry excavation may be considered.

- **Removal Efficiency.** Efficiency is the capability for removing the target contaminated sediment layer in a single (or minimum number of) pass(es) with the dredge equipment, while minimizing the quantity of over-dredged material to be treated and disposed. Where bedrock underlies contaminated sediments, removal by "over-dredging" to achieve low residual concentrations may be difficult or costly.

- **Contaminant Resuspension.** A major consideration is the capability for removing targeted sediments with minimum amount of sediment resuspension and loss during dredging.

- **Water Management.** Another selection criteria is practicality of managing large volumes of water associated with dredged material that will require collection and treatment prior to discharge of return flow to the river. This ranges from moderate amounts of free water and drainage arising from mechanically-dredged sediment to significant continuous volumes associated with return flow from a hydraulic dredge. Mechanical dredging and dry excavation produce smaller volumes of free water requiring treatment than hydraulic removal methods.

- **Equipment Availability.** Availability of dredging equipment is an important consideration. A number of floating clamshell dredges and small hydraulic dredges are available in the Great Lakes for use at the project site; however, the large quantity of PCB-impacted sediments located in the Lower Fox River and Green Bay may preclude equipment availability for long periods. Large construction backhoes and equipment barges are also available. However, many of the specialty dredges identified in the literature (e.g., pneumatic, refreshers, cleanup, matchbox dredges) are not available locally and/or would require fabrication of new dredging equipment and a period of operating experience.

- **Seasonal Restrictions.** *In-water work will occur within the months of April through October (an approximate 26-week time period).* A significant project constraint is the limited allowable work period for in-water construction activities. Freezing weather in winter will generally limit dredging to the months of April to October. In-water work near residential areas will be restricted to 10-hour work periods in order to minimize disturbance to the residents depending upon the nature of the work. For the purposes of the FS, all costs will be based on a 10-hour in-water work shift. The goal is to complete remediation activities within 10 years after initiation. The combination of sediment removal volume, sizing of pumps and equipment, dewatering facilities, and equipment type will influence the ability to meet the 10-year goal.

- **Work Sequencing.** Sediment removal will generally proceed from upstream to downstream in order to minimize the potential for recontamination of remediated downstream areas due to resuspension from upstream removal activities.

- **Access and Disposal.** Dredging can be limited by the ability to transport, dewater, and dispose of excavated material. A significant limiting constraint for dredging is the availability of on-land real estate for staging and support activities, as well as disposal options. The final destination of the excavated material will influence the type of dredging equipment selected. For example, if a nearshore CDF is considered, then hydraulic dredging and pumping directly into the CDF may be the best option.

- **The Lower Fox River Demonstration Projects.** Results of the Lower Fox River environmental dredging projects are essential considerations. The final selected remedy for a large-scale remediation effort will heavily depend upon the effectiveness of selected dredging equipment, containment systems, and dewatering operations of the pilot projects.

Implementability

Many regulatory and private interest groups are searching for answers to the same questions of how to cost-effectively manage contaminated sediments while ensuring protection of human health and the environment over the long term (Peterson *et al.*, 1999; Krantzberg *et al.*, 1999; Zarull *et al.*, 1999; SMWG, 1999; SPAC, 1997; Lower Fox River Group, 1998, 1999). Dredging is a common, well-developed technology that can be implemented in the Lower Fox River and Green Bay. Dredging is an effective technology utilized on numerous sites around the world for removing contaminated sediments.

Additionally, results of the Lower Fox River pilot projects demonstrate that dredging techniques can successfully remove a large mass of PCB-impacted sediments as well as achieve reductions in PCB sediment concentrations. Recent advances in dredge head construction and positioning technology enable accurate removal of sediment layers with minimum incidental over-dredging. However, concerns for sediment resuspension, surface recontamination, and downstream transport of impacted-sediments are commonly cited by dredging opponents as short-term limitations of the technology as a viable remedial alternative.

Results of the sediment technology review memo (Appendix B) indicate that dredging can be an implementable and effective method for managing contaminated sediments, provided that the technology is designed and managed appropriately for the site conditions. Expectations and project goals will also influence the perceived success of dredging projects along with a well-designed monitoring plan able to verify achievement of the intended goals. A few of the key concerns and findings are discussed below and detailed in Appendix B.

Sediment Resuspension. All removal technologies increase, to varying degrees, suspended solid concentrations in the surrounding waters. This resuspension may adversely impact localized water quality or result in spreading contaminated solids to clean sediment surfaces. Sediment resuspension can be managed by a combination of equipment selection and operational controls, including selection of an appropriate dredge type that best matches site conditions. Operator proficiency in placing and moving the dredge head, reduced dredging rates, and use of silt curtains can be important factors in limiting resuspension and spread of contaminated sediments. Field experience has shown that sediment resuspension by hydraulic dredges can be minimized by careful operation of the dredge (USACE, 1990). This involves controlling the speed of cutterhead rotation, the swing speed, the rate of dredge advance, and depth of cut. Recommendations for minimizing sediment resuspension at the dredge head include maintaining a slow to moderate cutter rotational speed at 15 to 20 revolutions per minute (rpm), a slow swing speed of 0.3 to 0.5 ft/s, and limiting the minimum cut depth to the range of 50 to 100 percent of the suction pipe diameter.

The cutterhead dredge was evaluated for removing contaminated sediment during the New Bedford Harbor Superfund Pilot Study. Compared to two other suction types, the cutterhead was superior for minimizing sediment resuspension (USACE, 1990). Round and horizontal auger cutterhead dredges was also used for removal of Deposit N and SMU 56/57 sediments, respectively.

Silt Curtains. Water quality impacts from sediment resuspension at the dredge may be reduced by conducting the dredging within a silt curtain, silt screen, or sheet pile enclosure in order to contain migration of the suspended solids/turbidity plume. A silt curtain is generally constructed of impermeable fabric and is suspended from the surface to the river bottom where it is anchored. A silt curtain can extend completely to the bottom with appropriate fringe weights and anchors.

Gravity settling of the denser sediment plume and loose re-settled solids will seek the lowest point, resulting in some migration beneath the silt curtain. Experience elsewhere indicates that a more than 90 percent reduction in suspended concentrations across the silt curtain can be achieved under favorable conditions. Silt curtains are not effective in current speeds above approximately 0.5 ft/s or in high winds or waves (EPA, 1994a).

In comparison, a silt screen is constructed of permeable fabric designed to pass water, but not the fine-grained resuspended sediment. Either the silt curtain or screen must be placed, managed, and removed with care to avoid resuspension and release of contaminated sediment during operations. Silt curtains and screen placement and operation may be a source of resuspension of bed sediment due to dragging or alteration of local currents. The need for and benefit of containment systems during dredging must be weighed against the utility of and potential disadvantages of these systems.

Maintaining a stable geotextile silt curtain was difficult in soft sediments at the Lower Fox River SMU 56/57 project in 1999. Passing boat traffic disrupted the integrity of the silt curtain, requiring immediate repair during the demonstration project. In 2000, the SMU 56/57 project successfully used silt curtains with sheet pile anchors to provide stability for the dredge. An 80-mil HDPE containment barrier was used at the Lower Fox River Deposit N demonstration project and successfully maintained for the duration of the project.

Surface Recontamination. Of the 20 projects reviewed in the *Sediment Technologies Memorandum* (Appendix B), 19 projects had lower maximum post-dredge surface concentrations than maximum pre-dredge conditions. The average percent reduction in maximum detected surface concentration was 84 percent (percent reduction in area average was 97 percent). For a few projects, it is fair to mention that the maximum concentration measured in residual sediments were occasionally higher than the target criteria; however, the majority of subunits measured, on average, were below the chemical criteria.

Surface concentrations should not be the sole measure of dredging success and risk reduction. The percent of surface area coverage with elevated surface concentrations above protective levels would be a more accurate measure of residual risk. For example, the Deposit N project in Wisconsin and GM Foundry project located in New York, collected confirmation samples from the cracks and crevices between the bedrock or bedrock itself because of insufficient sediment volume remaining above the bedrock (in some areas). These values likely biased the “true condition” of residual contaminant distribution among surface sediments. Moreover, focus on short-term residual surface concentrations remaining after dredging may misrepresent site risks. Removal of contaminant mass would likely be reflected in lower bioavailable surface concentrations over the long term as natural processes including sediment deposition and scour events occur over time.

Contaminant Transport. The PCB mass balance study conducted during Deposit N dredging activities (Water Resources Institute, 2000), estimated that less than 0.01 percent of PCBs from the slurry concentration was discharged back to the river after treatment. The mass balance model and the river turbidity samples consistently measured TSS below background values during project operations and did not measure an overall increase in mass of particles in the water column during dredging (TSS) when compared to upstream inputs. However, an increased net load of 2.2 kg of PCBs was transported downstream during the active dredging period. The majority of PCB mass excavated from the site (112 pounds) was successfully removed and contained within the treatment process, allowing only 2 percent of the PCB mass to escape the containment system.

Results of the Deposit N mass balance study concluded that surface water quality measures of turbidity or TSS were not accurate measures of PCB mass loading and transport. The Fox River Remediation Advisory Team recommended conducting a mass balance study (deposit mass balance, river transport, and process mass balance) for reliably measuring the transport effect of dredging operations.

Effectiveness

Effectiveness is described in terms of short-term effectiveness (ability to meet performance criteria) and long-term effectiveness (ability to achieve risk reduction). This evaluation of dredging effectiveness summarizes the finding of the *Sediment Technologies Memorandum* located in Appendix B. It also includes a brief summary of dredging, dewatering, and monitoring performance of the two pilot demonstration projects conducted on the Lower Fox River at Deposit N and SMU 56/57.

Ability to Meet Short-term Target Goals. Of the 20 projects reviewed in the *Sediment Technologies Memorandum* (Appendix B), 17 projects met their stated short-term project goals. The target goals were stated as sediment excavation to a chemical concentration, mass, horizon, elevation, or depth compliance criteria. In general, verification criteria that relied on physical features were generally assumed to remove the entire impacted sediment deposit based on site investigations. The two projects that did not meet their stated target goals were GM Foundry (cleanup criteria of 1 ppm PCBs), and Lower Fox River SMU 56/57 (cleanup to an elevation). One project, Manistique (cleanup criteria of 10 ppm PCBs) Harbor, has not been completed yet and therefore, results are undetermined.

Both the GM Foundry and Manistique projects made repeated dredging attempts to remove residual sediments resting on bedrock; however, confirmation samples were higher than the target goals for the maximum concentration detected. For the case of SMU 56/57, the contractor demobilized from the site before reaching the target elevation, thereby exposing the middle of the sediment deposit. This deficit was not a limitation of the dredging equipment; the equipment was capable of reaching the target elevation and removing the entire vertical profile of PCB mass. New contractors returned to the SMU 56/57 site in August 2000 under a different contract to remove the remaining PCB mass (see Appendix B).

Ability to Achieve Long-term Remedial Objectives. Achievement of long-term objectives are often measured as improved habitat quality, lower fish tissue concentrations, rescinded consumption advisories, and restoration of a site to beneficial use (e.g., parks, public areas). Of the 20 projects reviewed in the *Sediment Technologies Memorandum* (Appendix B), five projects met their stated long-term project objectives of protecting human health and the environment. Three of these projects (Bayou Bonfouca, Black River, and Minamata Bay) removed the fish consumption advisories listed for the project area within 7 years following remediation. The other two projects (Collingwood Harbour and Sitcum Waterway) were delisted from regulatory status. For Waukegan Harbor, the fish tissue concentrations in carp fillets showed a downward trend from pre-dredge conditions and the fish consumption advisories have been rescinded; however, the data are considered inconclusive because of small sample sizes. The fish tissue concentrations for most of the other projects showed preliminary decreasing trends, but additional sampling over time is required to determine trends. In many cases, the monitoring plans were not well defined nor implemented in order to distinguish site trends, nor has enough time elapsed since implementation to account for fish depuration rates.

Application to the Lower Fox River. The two Lower Fox River environmental dredging demonstration projects conducted at Deposit N and SMU 56/57 between 1998 and 2000 provided valuable feedback on the feasibility of dredging and dewatering sediments from the Lower Fox River. A summary of the field activities and performance/construction specifications for Deposit N and SMU 56/57 are summarized in Tables 6-8 and 6-9, respectively, and briefly described below. Detailed descriptions of the project design, implementation, monitoring activities, and lessons learned are presented as case studies in Appendix B.

The Lower Fox River Deposit N pilot demonstration project met the expected goals designed for the project. Due to the presence of a hard bedrock substrate located beneath the soft sediments, the target goal of the demonstration project was to remove contaminated sediment down to a design depth of 7.5 to 15 cm (3 to 6 inches) above bedrock. Approximately 5,475 m^3 (7,160 cy) of sediment and 50.3 kg (112 pounds) of PCBs were removed from Deposit N during 1998/1999 (Foth and Van Dyke, 2000). Overall, 82 percent of the PCB mass was removed from Deposit N and approximately 31 kg (68 pounds) of PCB remained in the sediments that were not accessible to dredging activities (Foth and Van Dyke, 2000).

The PCB mass balance study conducted during dredging activities (Water Resources Institute, 2000) estimated that the resulting press cake material contained 96 percent of the PCBs removed from the deposit and that less than 0.01 percent of PCBs from the slurry concentration was discharged back to the river. The mass balance model did not measure an overall increase in mass of particles transported downstream during dredging (TSS); however, the PCBs transported on the particles did increase (increased net load of 2.2 kg PCBs during the active dredging period). Currently, there are no further plans for additional work at Deposit N, now referred to as the former Deposit N.

The Lower Fox River SMU 56/57 pilot demonstration project removed approximately 81,000 cy of dredged material to the target elevations and met the expected goals designed for the project after returning to the site in 2000. Approximately 31,000 cy of dredged material was removed from SMU 56/57 in 1999, leaving a large portion of the contaminated material behind before equipment was demobilized for the winter. Under an EPA Administrative Order by Consent (AOC No. V-W-00-C-596), the Fort James Corporation continued sediment remediation activities at SMU 56/57 during the summer of 2000. Additional contaminated sediment (50,000 cy) was removed in 2000 from subunits that were previously disturbed (dredged) during the 1999 pilot project.

In 1999, the target goal of the SMU 56/57 project was to dredge to a design elevation of 565 feet (MSL, National Geodetic Vertical Datum 1929 [NGVD29]). Dredging to this design elevation was expected to remove sediments with PCB concentrations greater than 1 ppm. Confirmation sampling was compared to 1 ppm PCBs. However, the target elevation was not achieved in any of the subunits within the dredge prism. Due to the difficulties encountered during dredging and the onset of winter, the expected elevation was raised 2 to 3 feet in most areas. A final "cleanup pass" initially intended for all areas was only completed in 4 of the 59 subareas (WDNR, 2000a). In these areas, the final PCB concentrations in the newly exposed surface sediments showed a general decline compared with pre-dredging concentrations, and in some locations the final PCB concentrations were as low as 0.25 ppm. However, in other areas where no final pass was completed down to the targeted sediment elevations, the final PCB concentrations were higher (32 to 280 ppm) than baseline surface concentrations

(2 to 5 ppm). In 1999, the post-dredge average residual PCB concentration was 7.5 ppm (40% reduction from 11.7 ppm average).

Lessons learned during the 1999 removal effort were successfully applied to the 2000 removal effort. For instance, equipment difficulties and large debris was encountered during 1999 dredging which hindered progress and production rates. The auger cutterhead dredge produced a sediment slurry with 4.5 percent solids; much lower than the design specifications. The dredge needed shorter cables, better positioning, and more overlapping transects to remove residual sediment ridges. During early stages of the project, coal ships docking at the Fort James facility disturbed the silt curtain, ripping it from its moorings on at least one occasion. Also, the liner of one of the two settling ponds was damaged during October 1999, requiring discontinued use of that pond until the liner could be repaired. Dredging was suspended on December 15, 1999, due to ice on the river and icing of the wastewater treatment system. In 2000, equipment was mobilized to the site 1 month earlier to lengthen the available dredging window before the onset of winter conditions. Land-based excavation equipment conducted a pre-removal of large boulders and debris before mobilization of the hydraulic dredge. The percent solids of the sediment dredge slurry averaged 8.4 percent, almost double the percent solids obtained during 1999. In 2000, a different silt curtain system was used and the passive dewatering equalization basins were eliminated and slurry was pumped directly to holding tanks.

In 2000, the Lower Fox River SMU 56/57 dredging project removed approximately 50,000 cy of sediment to the target elevation of 565 feet MSL. Post-verification surface sediment samples ranged from non-detect to 9.5 ppm (average 2.2 ppm) after one cleanup pass (target goal was less than 10 ppm). A 6-inch cap was placed over areas where surface sediment was above 1 ppm PCBs (no cap necessary if sediment was less than 1 ppm). More cleanup passes were not conducted because the contractor prioritized placement of the cap prior to onset of winter conditions.

Dredging Costs

As summarized in the *Sediment Technologies Memorandum* (Appendix B), dredging costs range from \$6 to \$500 per cubic yard. Costs are dependent upon understanding site conditions, extent of containment and monitoring, removal volumes, project expectations, and appropriateness of selected technologies. Total project costs including project planning, dredging, treatment, disposal, redevelopment (in some cases), and long-term monitoring can range from \$0.6 million to \$50 million. More detailed dredging and disposal costs are described in Appendix B.

Screening Decision

Dredging is retained as a removal technology for development of sediment cleanup alternatives (Table 6-4). Dredging has been successfully implemented in the Lower Fox River and elsewhere in the Great Lakes system as a tool for sediment remediation. Hydraulic dredging technologies (round cutterhead and horizontal auger) and process equipment may be effective methods for removing contaminated sediments from the Lower Fox River when properly designed, communicated, and implemented. Mechanical and hydraulic dredges are primary process options likely to be used in sediment removal operations; however, dry excavation may also be retained for shallow areas. Depending on site characteristics, both could be used at different locations within a single reach of the Lower Fox River or section of Green Bay.

6.4.6 *In-situ* Treatment

In-situ treatment of sediments refers to chemical, physical, or biological techniques for reducing COC concentrations while leaving the impacted sediment mass in place. *In-situ* technologies are commonly employed for cleanup of contaminated soil and groundwater. No successful adaptations of these and other technologies to full-scale sediment cleanup involving PCBs have been reported in the literature. Table 6-3 presents the results of feasibility screening for several potential *in-situ* treatment technologies. None are feasible for implementation in the Lower Fox River and Green Bay (Table 6-5).

6.4.7 *Ex-situ* Treatment

Ex-situ treatment refers to the processing of dredged sediments to transform or destroy COCs. Table 6-5 screens *ex-situ* treatment technologies based on implementability and effectiveness.

Description of *Ex-situ* Treatment Process Options

Treatment processes may be classified as biological, chemical, physical, or thermal. *Ex-situ* thermal treatment includes three subcategories: incineration, high-temperature thermal desorption (HTTD), and vitrification. All of these treatment technologies were retained for consideration in the initial FS screening process; however, only thermal treatment was retained for the final screening.

Biological. Biological treatment methods involve amendments of nutrients, enzymes, oxygen, or other additives to enhance and encourage biological breakdown of contaminants. Inorganics (metals) and PCBs are not well suited to biological treatment techniques. There are no proven and effective biological techniques for treating PCBs full scale and no reports in the literature of PCB-contaminated sediments biotreated *ex situ*. A pilot-scale biological treatment study was conducted on PCB-impacted sediments from the Sheboygan River, Wisconsin and the Hudson River, New York, but neither the aerobic nor anaerobic treatment had a significant effect (BBL, 1995).

Chemical. Chemical treatment methods involve the addition of acids/solvents to extract contaminants or oxidizing agents to encourage conversion to less hazardous compounds. Chemical methods for treating contaminated sediments show little promise. Acid extraction is ineffective for treatment of PCB-contaminated sediments. Solvent extraction is specific to soluble organics (e.g., PCBs) and some organic-complexed metals. Other inorganics remain in the sediments requiring some other form of treatment or disposal. Further, additional treatment is required for the concentrated extract. The literature provides no reports of chemical technologies implemented full-scale for the treatment of sediments.

Physical. Physical separation or soil washing refers to the process of classifying sediment into fractions according to particle size or density. Separation may be accomplished by screening, gravity settling, flotation, or hydraulic classification using devices such as hydrocyclones (USACE-DOER, 2000a). Equipment for physical separation is widely available, and the concept has been demonstrated for sediments in both the United States and Europe (USACE-DOER, 2000a); however, physical treatment methods have limited application for removing PCBs from contaminated sediments. Physical separation involving removal of the larger sand and gravel fraction from finer-grained sediment may or may not reduce the residual contaminated sediment mass and/or volume.

Physical treatment can also refer to the solidification/stabilization of dredged material to reduce the mobility of constituents through the use of immobilization additives. Many additives commercially available can immobilize both organic and inorganic constituents. Solidification reagents often include: Type I Portland cement, pozzolan, cement kiln dust, lime kiln dust, lime fines, and other proprietary agents. As described in the *Basis of Design Report for the Lower Fox River SMU 56/57 Project* (Montgomery-Watson, 1998), bench-scale solidification studies using Portland cement and lime dust were tested on dredged material from the Lower Fox River; the lime performed better. In bench-scale studies conducted on PCB-impacted sediments from the Sheboygan River (BBL, 1995), the Portland cement additive provided desirable physical characteristics (i.e., compressive strength) and leachability characteristics.

Thermal. Thermal treatment technologies desorb and subsequently destroy organic compounds by combustion. Thermal process options may be grouped into the categories of incineration, thermal desorption, and vitrification. The former two options are widely practiced technologies for treatment of soil containing PCBs and other organics. Vitrification was developed initially for use in treating radioactive mixed wastes and is receiving attention as a cost-competitive thermal option for treating soils and sediments high in sand content. Regardless of the specific technology option, thermal treatment requires that sediments first be dewatered to reduce water content and therefore the amount of heating energy required.

Incineration. Incineration temperatures are typically between 1,400 and 2,200 degrees Fahrenheit (˚F) which is sufficient to volatilize and combust organic chemicals. A common incinerator design is the rotary kiln equipped with an afterburner, a solids quench (to reduce the temperature of the treated material), and an air pollution control system. Incinerator off-gases require treatment to remove particulates and neutralize and remove acid gases. Baghouses, venturi scrubbers, and wet electrostatic precipitators remove particulates; packed-bed scrubbers and spray driers remove acid gases. Baghouses, venturi scrubbers, and wet electrostatic precipitators remove particulates; packed-bed scrubbers and spray driers remove acid gases. Incineration facilities are generally fixed-based. Mobile incinerators are available for movement to a fixed location in close proximity to the contaminated sediments. Incineration of PAH-contaminated sediment was successfully conducted at the Bayou Bonfouca Superfund site, Louisiana, at a unit cost of $154 per cubic yard. Residual incinerator ash was placed in an on-site landfill.

High-temperature Thermal Desorption. High-temperature thermal desorption (HTTD) is a full-scale technology in which temperatures in the range of 600 to 1,200 ˚F volatilize organic chemicals. HTTD desorption efficiencies for removing PCBs from sediment range between 90 and 99 percent. A carrier gas or vacuum system transports volatilized water and organics to a condenser or a gas treatment system. After sediment desorption in the HTTD unit, volatilized organics are destroyed in an afterburner operating at approximately 2,000 ˚F. This treatment technique has been used successfully at several other sites with PCB contamination. HTTD systems can be both fixed-based and transportable and typically use a rotary kiln. HTTD is a commonly used technology for soils and is readily adapted to sediments. Capacities on the order of 100 tons per hour are available in transportable models.

An anaerobic thermal processor (ATP) extraction system operated by Soil Tech successfully treated PCB-contaminated sediment from the Waukegan Harbor site in Illinois. The ATP system treated sediments with greater than 500 ppm PCBs with an average PCB removal efficiency of 99.98 percent (Appendix B). Air emissions met the 99.9999 percent destruction removal efficiency (DRE) stack emission requirement for final destruction of PCBs.

Vitrification. Vitrification is a process in which high temperatures (2,500 to 3,000 °F) are used to destroy organic chemicals by melting the contaminated soil and sediments into a glass aggregate product. Vitrification units can be operated to achieve 99.9999 percent destruction and removal efficiency requirement for PCBs and dioxin. Trace metals are trapped within the leach-resistant inert glass matrix. Various types of vitrification units exist that utilize different techniques to melt the sediments, including electricity and natural gas, and are discussed in detail below. The following references and project summaries were used in this FS Report to assess the applicability of vitrification technology:

- *Decontamination and Beneficial Reuse of Dredged Estuarine Sediment: The Westinghouse Plasma Vitrification Process* (McLaughlin *et al.*, 1999);

- *Glass Aggregate Feasibility Study - Phase I and II* (Minergy Corporation, 1999);

- *Final Report: Sediment Melter Demonstration Project* (Minergy Corporation, 2002a); and

- *Unit Cost Study for Commercial-Scale Sediment Melter Facility, Supplement to Glass Aggregate Feasibility Study* (Minergy Corporation, 2002b).

Plasma Vitrification Process. This process involves superheating air by passing it through electrodes of the plasma torch. Partially screened and dewatered sediment is injected into the plume of the torch and heated rapidly. After dredging, sediment must be dewatered to approximately 50 percent solids. Additional drying is required to further reduce moisture. Rotary steam-tube dryers or other indirectly heated drying systems are used for this purpose. The high temperature combusts and destroys all the organic contaminants and the mineral phase melts into a glass matrix. Fluxing agents such as calcium carbonate, aluminum oxide, and silica oxide are blended with the sediment, as needed, to obtain the desired molten glass viscosity. The molten glass is quickly quenched, resulting in a product suitable for a wide variety of applications.

Glass Furnace Technology. This process uses a state-of-the-art oxy-fuel-fired glass furnace to vitrify sediment into an inert glass aggregate product. Sediment is dewatered and partially dried before being fed into the glass furnace. The high temperature melts the sediments resulting in a homogenous glassy liquid. Additives such as calcium carbonate, aluminum oxide, and silica oxide are added to obtain the desired viscosity of molten glass. The molten glass is collected and cooled quickly in a water quench to form glass aggregate product. The final glass product has a wide range of industrial applications.

During the comment period of the 2001 draft of the Lower Fox River RI/FS, WDNR completed a project to evaluate the feasibility of a vitrification technology, based on standard glass furnace technology, to treat contaminated river sediment. The sediments treatment demonstration project was completed in 2001 under the EPA's Superfund Innovative Technology Evaluation (SITE) program. A summary of the sediment melter demonstration project with performance and construction specifications is summarized in Table 6-11. Detailed descriptions of the treatment process, process design and construction, observations, and cost estimates are provided in Appendix G.

Screening Criteria for *Ex-situ* Treatment Selection

This screening evaluation focuses on thermal technologies, as neither biological nor chemical/physical treatments are feasible for application in the Lower Fox River and Green Bay.

Implementability

Chemical and biological treatment technologies have not been implemented nor proven successful for PCB sediment remediation. Physical separation may be feasible for sediment dredged from the Lower Fox River, but this technology has not been included in the alternatives analysis. Incineration, HTTD, and vitrification are viable thermal technologies for treatment of PCBs in dredged sediment. Incineration and HTTD are well-developed technologies and are commonly used for treatment of PCB-contaminated soil. Vitrification has not been used full scale for treatment of contaminated sediments. However, based on the multi-phased feasibility study conducted by WDNR in 2001, this technology appears to be a viable option for application to sediments in the Lower Fox River.

Many sediment remediation projects in Europe require physical separation of the sand/silt fractions to minimize the sediment volumes requiring disposal, due to limited disposal options. Sediment removal costs and implementability depends upon the contaminant of concern, grain size distribution, and amount of debris in the substrate matrix. Sand reclamation costs for operation of a small plant that handles 150,000 to 200,000 m^3 annually costs \$35 per m^3 of sediment treated (McLellan and Hopman, 2000). A successful sand reclamation project was implemented at the Port of Rotterdam, Netherlands site (McLellan and Hopman, 2000). Hydrocyclones and "sand peelers" separate sand from the fine fraction and reuse the sand for industrial purposes and preserving disposal capacity at a 100 million m^3 nearshore fill. Sand reclamation may be considered during the design phase of the Lower Fox River/Green Bay project, but is not considered in this FS. However, physical treatment expressed as sediment dewatering is required to prepare the sediment solids for treatment and disposal and therefore, is not discussed separately.

Thermal processes must meet TSCA testing and air performance requirements specified in CFR 40 Part 761.70(b) if sediment PCB concentrations exceed 50 ppm. The glass furnace vitrification process evaluated for Lower Fox River sediments requires construction of a new melter facility. The plant size is dependent on the amount of dredged and dewatered sediment available for processing. The sediments feed rate through the melter is limited by the capacity of the facility and moisture content of the sediments. Dewatered sediments need to be mixed with drier materials to achieve optimum moisture content of 37 percent to prevent agglomeration and facilitate easy material handling. The dryer must further reduce the sediment moisture content to 10 percent prior to processing in the melter (Minergy Corporation, 2002a).

Effectiveness

Thermal desorption systems generally perform at lower destruction/removal efficiency than incineration systems. Thermal desorption removal efficiencies are generally in the neighborhood of 90 to 99 percent (Garbaciak and Miller, 1995). As stated earlier, biological and chemical treatment are likely to have little effect on site sediments. Physical treatment can effectively remove coarse-fractioned solids from dredged material and provide adequate physical characteristics needed for disposal.

River sediments processed during Phase III of the WDNR glass furnace demonstration project conducted in 2001 achieved a PCB destruction of greater than 99.99993 percent. The glass aggregate was subjected to both ASTM water leaching procedures and SPLP testing. The ASTM water leaching procedures and SPLP test did not detect any PCB congeners, SVOCs, or any of the eight heavy metals. Dioxins and furans were not generated during the sediment treatment process. The end product created by the treatment process was very consistent, producing a hard, dark granular material. The resulting glass aggregate has a wide range of industrial applications including roofing shingle granules, industrial abrasives, ceramic floor tile, cement pozzolan, and construction fill (Minergy Corporation, 2002a).

Treatment Costs

Exclusive of material preparation costs (e.g., dewatering), thermal treatment unit costs can range from $25 to $1,000 per ton (EPA, 1994a). Depending on the size of vitrification unit, unit costs range between $27 and $57 per ton (Minergy Corporation, 2002b). Detailed cost breakdowns and analysis are provided in the *Unit Cost Study for Commercial-Scale Sediment Melter Facility* provided in Appendix G.

Screening Decision

No biological or chemical treatment technologies are retained for development of remedial alternatives in Section 7. All three thermal technologies (incineration, vitrification, and HTTD) are implementable and effective for treatment of PCBs in sediments. Physical treatment is retained as a dewatering process option (ancillary technology).

6.4.8 Disposal Process Options

Disposal is the relocation and placement of removed sediments into a site, structure, or facility (e.g., landfill). Disposal is the most frequent endpoint for sediments in remediation projects that involve removal. PCB-contaminated sediment removed from the Lower Fox River can be disposed of at a number of upland disposal facilities, and depending upon the PCB concentration, in "in-water" contained aquatic disposal (CAD), or level-bottom caps.

Description of Disposal Process Options

Four general disposal options exist for the disposal of PCB-impacted sediments removed from the Lower Fox River. These are:

- Level-bottom cap;
- Confined aquatic disposal (CAD);
- Existing landfill (in- or out-of-state), construction of new, dedicated landfill; and
- Confined disposal facility (CDF).

Level-bottom Cap. Level-bottom capping involves the mounding of contaminated sediment in an area of a water body that has a relatively flat bottom. Capping material is then placed on top of the mounded sediments. The cap must be designed to prevent scour and erosion. Level-bottom caps have typically been constructed in large water bodies such as oceans or lakes. Applications in river systems are uncommon because of water depth requirements for navigation and recreation, as well as the potential scouring that can occur during high-flow periods.

Confined Aquatic Disposal. Confined aquatic disposal (CAD) is similar to level-bottom capping, with the exception that the contaminated sediments have lateral sidewall containment from an engineered berm or as a result of excavating a depression at the disposal site (Figure 6-7). As with level-bottom capping, the cap must be designed to prevent scour, erosion, and bioturbation. CAD applications in river systems are uncommon because of water depth requirements for navigation and recreation, as well as the potential scouring that can occur during high-flow periods. Thus, construction of a CAD facility is likely restricted to Green Bay.

The deposit site is prepared either by excavating a depression and using the excavated material for construction of a perimeter berm, or by importing material to construct a perimeter berm on the existing sediment surface. The contaminated sediment is deposited at the specified location and topped with clean sediments.

Existing or Proposed In-state Landfills. A landfill is an engineered facility that provides long-term isolation and disposal of waste material, thereby minimizing the potential for release of contaminants to the environment. Landfills are designed to prevent the release of contaminants to groundwater, control runoff to surface water, and limit dispersion into the air.

Landfills in Wisconsin must meet location, hydrogeologic evaluation, and groundwater performance standards (NR 500 WAC). Landfill design requirements in Wisconsin also include: 1) a cover system, 2) a liner system, 3) a leachate collection and treatment system, 4) a water monitoring system, and 5) a gas monitoring system. Landfills cannot accept wastes containing free liquids and sediments must first be dewatered or stabilized before disposal. A total of 13 existing landfills are located within a 40-mile radius of Green Bay, Wisconsin (Figure 6-8).

Construction of New, Dedicated Landfill. Contaminated sediment may also be placed within dedicated cells, or monofills, located within landfills. The monofill provides additional assurances that the contaminated sediment will not mix with other solid waste, and provides for more stable long-term control of the material.

Confined Disposal Facility. A confined disposal facility (CDF) is an engineered containment structure that provides for dewatering and permanent storage of dredged sediments. In essence, CDFs feature both solids separation and landfill capabilities (EPA, 1994a). Containment of contaminated sediments in CDFs is generally viewed as a cost-effective remedial option at Superfund sites (EPA, 1996b). Recent interest in CDFs for disposal of contaminated dredged sediment has led both the USACE and the EPA to develop detailed guidance documents for construction and management. These include:

- *Engineering and Design - Confined Disposal of Dredged Material* (USACE, 1987);

- *Design, Performance, and Monitoring of Dredged Material Confined Disposal Facilities in Region 5* (EPA, 1996b);

- *Confined Disposal Facility (CDF) Containment Features: A Summary of Field Experience* (USACE-DOER, 2000b);

- *Assessment and Remediation of Contaminated Sediments (ARCS) Program Remediation Guidance Document* (EPA, 1994a);

- *Verification of Procedures for Designing Dredged Material Containment Areas for Solids Retention* (Averett *et al.*, 1988); and

- *Comprehensive Analysis of Migration Pathways (CAMP): Contaminant Migration Pathways at Confined Dredged Material Disposal Facilities* (Brannon *et al.*, 1990).

A CDF may be constructed as an upland or floodplain site, as a nearshore site (one or more sides exposed to water), or as an in-water island containment area. For the purposes of this FS, only the in-water, nearshore and floodplain CDFs are considered. There are approximately 50 completed CDFs in the Great Lakes region. These facilities were constructed primarily for dredged material from navigation projects. Most of the CDFs are in-water lakefills that were constructed using stone retention dikes and simple water return systems. The remainder are upland facilities constructed with earthen dikes, or placed within existing or excavated depressions. Nearshore CDFs have been successfully completed at the Waukegan Harbor, Illinois and Sitcum Waterway, Washington sites for contaminated sediments (Appendix B).

There are two types of designs that are used in the construction of a CDF: solids retention and hydraulic isolation. Solids retention designs for CDFs physically isolate the sediment solids from the environment. Solids retention designs are used when the contaminants in the sediment are tightly bound to the retained solids and are not likely to leach and contaminate the surface or groundwater. Designs for these types of CDFs need only consider retention dikes or configurations such as geosynthetic liners placed between the inner wall of the retention dike and the dredged material. The design of in-water CDFs must consider a final construction height of at least 6 feet above the normal river level (the 100-year flood level) in order to maintain the surface above maximum expected flood height. External dike construction would need to consider the potential for flood- or ice-induced damage. Water treatment consists of settling out the particulates prior to discharge. An example of an in-water CDF is illustrated on Figures 6-9 and 6-10.

In contrast, hydraulic isolation designs isolate the solids and capture the associated water from the contaminated solids. Design of these facilities are similar to those for NR 500 WAC landfills and often employ extensive water recovery and treatment operations. For costing purposes in the FS, we have assumed a 6-foot berm level for all remediation areas, which is the approximate elevation gain increase in lower Green Bay for the 100-year flood event.

Regulatory Considerations

Open-water Disposal. Open-water disposal of contaminated sediments is banned in the waters of Wisconsin (Appendix C). The ban exists in Wisconsin Statutes Chapter 30.12(1)(a). There are, however, certain exceptions to the open-water disposal prohibition. The exceptions include: 1) legislative authorization, 2) lakebed grants, 3) bulkhead lines, and 4) leases. Obtaining any of these exceptions for disposal of dredged material into navigable water may be utilized for remediation of the Lower Fox River (Lynch, 1998), but each could require substantial time to obtain. To obtain an exemption, the activity must still meet the conditions and limitations of the state's responsibilities for protection of water quality and other related issues. This ban applies to level-bottom capping and construction of a CAD or CDF site. Thus, special approval by the state legislature addressing provisions of this ban would be required to implement open-water remedies. This option, by use of a lakebed grant, could be applied to a CDF where the title of a lakebed or bed of a waterway would be transferred from the state to a municipality.

Placement in an Upland Landfill. Dredged sediment is classified as solid waste in Wisconsin (Lynch, 1997, 1998). This determination has been made through statute and case law. Wisconsin Statute Chapter 289 and NR 500 through 520 of the WAC provide most of the regulatory framework for handling and disposing of solid waste, and therefore, dredged contaminated sediments. Additionally, in a January 24, 1995 agreement, the EPA gave WDNR the authority to manage the disposal of sediment contaminated with PCBs in concentrations of 50 ppm or greater in NR 500 WAC-approved landfills. Sediments containing PCBs of 50 ppm or greater may be disposed in an NR 500 WAC-approved landfill with EPA concurrence. A copy of the agreement (EPA, 1995b) is included in Appendix C. The agreement also allows WDNR to "select disposal facilities that comply with NR 500 through 520 WAC for the disposal of sediments contaminated with PCBs at concentrations of 50 ppm or greater from sediment remediation projects conducted under the authority and supervision of the WDNR" (EPA, 1995b). Any landfill approved for disposal of contaminated sediment must meet the stringent state requirements for the design, operation, and maintenance of a Subtitle D landfill. In other words, TSCA approval issued from EPA Region 5 is only applicable to landfills that go through the landfill siting and licensing process.

WDNR has the authority to issue exemptions from regulation under Wisconsin Statutes Chapter 289, under some circumstances. The primary exemptions which cover dredged material exist in WAC NR 500.08(3) (Beneficial Reuse). The exemptions may not apply to sediment from the Lower Fox River and Green Bay (Lynch, 1998) because of the large volumes of sediment and the concentrations of PCBs within the sediments.

Other exemptions from solid waste regulations for dredged material are found in the Wisconsin Statutes Chapter 289.43(8), and related NR 500 WAC state codes. The exemption is known as the "Low Hazard Exemption." The Low Hazard Exemption allows exemptions from landfill siting roles and state statutes for either beneficial reuse or disposal. This exemption has been used in the past for nonhazardous dredged material (below TSCA levels *in situ*) generated from the Lower Fox River. The low-hazard waste grant of exemption is a possibility for at least some of the dredged material in the Lower Fox River, either for beneficial reuse or disposal.

New, Dedicated Upland Landfill. Construction of a new publically-owned, upland landfill dedicated to the disposal of sediments is a potential option. A dedicated and centrally-located facility would allow reasonable access from all areas of the river. The total capacity required may be up to 5,000,000 cy for the De Pere to Green Bay Reach. Construction requirements for a dedicated landfill would generally be the same as the construction requirements for a municipal landfill. It is important to note that the process of gaining approval for the location of a new landfill (the siting process, as detailed in Wisconsin Statutes Chapter 289) is lengthy and may take many months or years to complete (Huebner, 1996).

A new landfill dedicated to disposal of dredged material (and would not be used for municipal solid wastes) may be exempt from the free liquids and shear strength requirements of solid waste landfills. If the site is designed to accommodate the properties of dredged material (e.g., leachate collection system), then many of the physical requirements of the material may not apply.

Confined Disposal Facility. CDFs are disposal facilities located within a floodplain or a waterway and cannot be permitted through the landfill siting process. The mechanisms are available to permit this disposal option if there is a strong rationale to do so. One limitation to this option is the potential long period of time required to obtain the appropriate permits. Wisconsin has banned open-water disposal of dredged material on the bed of all navigable waters for more than 25 years.

In addition to the Wisconsin Statute Chapter 30 ban, NR 504 WAC provides for certain setback requirements when siting disposal facilities. Disposal facilities are required to be set back certain distances from water ways and floodplains. The WDNR has the authority to waive this requirement under Wisconsin Statute Chapter 289.

Floodplain and in-water CDFs can only be designed for nonhazardous solid waste and dredged material generated from non-TSCA-level sediments. In-water CDFs are unlikely to be permitted for sediment with PCB concentrations exceeding the TSCA limit of 50 ppm. As described previously for capping, EPA has not, to date, permitted any permanent in-water containment facilities.

CERCLA Exemptions. CERCLA exempts permitting requirements for "on-site" disposal facilities if the EPA is conducting the remediation, or has issued an order or signed a consent decree with the principal responsible parties (PRPs). The exemption does not apply if the State of Wisconsin conducts the work or issues the order or consent decree. For remediation of the Lower Fox River and Green Bay, WDNR's position is that disposal units adjacent to the river or in water could be considered "on-site." Additionally, WDNR does not believe that locational criteria ARARs for on-site disposal units could be exempted or waived even under an EPA-led CERCLA action (Lynch, 1998).

Screening Criteria for Disposal Selection

The criteria used for selection of a disposal alternative are primarily based on location, capacity, access, and long-term stability. Off-site disposal is considered potentially feasible for all river reach and bay alternatives requiring disposal. Final selection of disposal options will depend upon several criteria (EPA, 1994a):

- Location,
- Upland land use,
- Fill capacity,
- Length and quality of haul route,
- Site setting and design,
- Residential impacts,
- Multiple disposal locations,
- Regulatory considerations,
- Contaminant concentration, and
- Flood and erosion control.

Implementability

Level-bottom Cap. From a technical standpoint, a level-bottom cap is a reasonable disposal option for contaminated sediments in Green Bay. Deep and quiescent areas of Green Bay located away from navigation channels may afford the long-term stability necessary to ensure that COCs are not released back into the aquatic system through erosion.

The effectiveness of level-bottom capping is similar to that of other capping approaches (Section 6.4.4). As long as the design criteria are met, a level-bottom cap contains the contaminated sediments and prevents exposure to humans and aquatic organisms.

Confined Aquatic Disposal. From a technical standpoint, a CAD is a reasonable disposal option for contaminated sediments in Green Bay. Deep and quiescent areas of Green Bay located away from navigation channels may afford the long-term stability necessary to ensure that COCs are not released back into the aquatic system through erosion. The short-term impacts of contaminant loss to the water column during placement of the dredged sediments must be considered. Several placement equipment options along with use of engineering controls during placement can reduce losses. Results of empirical tests and computer modeling allows for prediction of contaminant losses during placement and aids in selection of the placement technique.

Monitoring and maintenance (if required) are essential components of a CAD project. Monitoring determines the extent to which CAD performance is matching design expectation in terms of preventing contaminant exposures.

Landfill. There are no technical obstacles related to the disposal of dredged sediments in landfills. With the exception of dewatering to an acceptable moisture content, sediment must merely meet the applicable acceptance criteria of the landfill.

If the dredge slurry is pumped directly to a disposal site located a few miles away from the dredge area (i.e., greater than 5 miles), then a detailed engineering design evaluation would be required to successfully pump the slurry large distances. Long slurry pipe runs are technically feasible as demonstrated in White Rock Lake, Dallas, Texas. A 20-mile-long steel, 24-inch-diameter dredge slurry pipe run extended from the dredge area in White Rock Lake through residential and commercial areas directly to a former sand and gravel quarry disposal site (Sosnin, 1998).

Confined Disposal Facility. CDFs are implementable from an engineering standpoint. As long as site conditions, placement constraints, and regulatory criteria are satisfied, construction and placement in a CDF is a reasonable disposal option for both the river and bay. A CDF could be technically designed to adequately isolate contaminated sediments over the long term.

Effectiveness

Disposal at a single location presents a long-term liability at a single facility. Disposal of the sediments at multiple locations may incrementally increase the overall long-term liability of the sediments. By disposing at numerous facilities, there is potential long-term liability associated with the waste disposed at each facility.

Level-bottom Caps. The most notable use of level-bottom capping techniques is the open-water multi-user New York Mud Dump Disposal Site operated through the Disposal Area Monitoring System (DAMOS) Program. This program uses level-bottom cap placement and containment technology to confine low- to moderately-contaminated sediments. This site is regularly monitored to ensure compliance within the confines of the program (USACE, 1995).

Confined Aquatic Disposal. The long-term effectiveness of a CAD is similar to that of other capping approaches (Section 6.4.4). The primary criteria for success is that the cap thickness required to isolate contaminated material from the environment be placed correctly and maintained. CAD experience demonstrates that proper site selection, design, and construction can eliminate resuspension due to bioturbation and erosion. Further chemical diffusion of contaminants through a properly designed cap is negligible and does not present a long-term risk to the environment.

Landfills. Table 6-10 lists municipal and non-municipal landfills located within the Lower Fox River valley and provides information about existing and proposed capacities. Information in the table was derived from WDNR records (WDNR, 1998). Approximately 14 existing and proposed municipal and non-municipal landfills exist within 40 miles of the Lower Fox River. Capacities for all the landfills were not available. Figure 6-8 shows the general location of these landfills.

Waste disposal capacity of landfills located within 40 miles of the river is in excess of 30 million cubic yards. Although several municipalities banned disposal of contaminated sediment in landfills in the past, most local governments have either removed the bans or are in the process of removing the bans, opening the way to additional landfill capacity in the Lower Fox River valley.

Disposal at out-of-state landfills may be an option if in-state disposal facilities have insufficient capacity or cannot be used for other reasons (e.g., permit restrictions). Other disposal locations may become available in the future. Adequate space will most likely exist in municipal and non-municipal landfills within 40 miles of the Lower Fox River to accept all sediments removed from the river, if this option is selected.

Preliminary engineering work has been completed for at least one landfill facility capable of accepting contaminated sediment from the Lower Fox River. The planned facility is located within 20 miles of the Lower Fox River in rural Brown County. The quantity of impacted sediment is compared to typical one-time solid waste disposal projects. The current capacity of landfills will determine the amount of sediment that can be disposed of at any landfill.

Confined Disposal Facility. As previously discussed, several CDFs have been constructed for disposal of contaminated sediments and considerable support is available in the literature for design and construction. Over 10 nearshore CDFs have been placed in Puget Sound (West Eagle Harbor, Washington; Sitcum/Milwaukee Waterway, Washington), the Great Lakes region (Calumet Harbor, Chicago; Waukegan Harbor, Illinois), and east coast (New Bedford Harbor, Massachusetts) combined (USACE-DOER, 2000b). Several isolated in-water cells have been placed in Europe and the United States.

Siting, acceptance by the public and regulatory communities, as well as permitting are central to the implementability of this disposal option. In-water CDFs would be limited to areas of the Lower Fox River that are relatively wide with general construction access. Likewise, floodplain CDFs would be limited to large near-river locations that could be permitted for landfill use. In-water CDFs would need to consider site access and potential losses of lake frontage to upland riparian landowners. Other potential uses of the Lower Fox River by upland owners, such as intake or permitted wastewater discharge pipes, and electrical or other cable crossing, must be considered in locating an in-water CDF.

Due to its size, large areas of Green Bay are suitable for siting a CDF.

Floodplain and in-water CDFs would need to meet the substantive requirements for landfills defined in NR 500 WAC. While PCBs alone might be considered particulate-bound contaminants and a simple solids retention design might be suitable, dredged sediments in the Lower Fox River and Green Bay will also contain quantities of other metals, pesticides, and semivolatile organic compounds (i.e., polyaromatic hydrocarbons) that may require some consideration of hydraulic control (i.e., collection of internal leachate; physical isolation).

Disposal of contaminated sediments in CDFs is an effective means of isolating COCs from the surrounding environment. As with other disposal options, CDFs prevent exposure of humans and aquatic organisms to the contaminants.

Migration of COCs out of a CDF over the long term is precluded through design features and the fact that the PCBs are strongly sorbed to the sediment particles.

Disposal Costs

Level-bottom capping and CAD sites are generally lower in cost than other engineered disposal options such as confined disposal facilities. Level-bottom capping is the lowest-cost disposal option for contaminated sediments as the material is merely deposited in a mound at a specific location and topped with clean sediments. Disposal costs for construction and filling of a CDF is expected to be comparable to landfill disposal (which includes transport). Landfill disposal costs typically range from $25 to $50 per ton exclusive of transportation. Disposal at out-of-state landfills would generally be more costly than disposal at existing local or regional in-state landfills or new dedicated landfills because of increased transportation costs.

Estimated costs to acquire and build the approximately 4 million-cubic-yard landfill currently planned in rural Brown County to accept contaminated sediment is $14 million plus a local siting fee of $5 per ton. Operating costs of the landfill were estimated at $500,000 per year for 10 years. Landfill closure was assumed to consist of a typical cap at $100,000 per acre. Post-closure O&M costs are estimated to be $30,000 per year for 40 years.

Screening Decision

Level-bottom capping and confined aquatic disposal are viable technologies for disposal of contaminated sediments in Green Bay as long as the statutory restrictions on open-water disposal can be accommodated. Dredged material located in an upland landfill could be subsequently removed for treatment, if desired, and would be more accessible for removal than in-water disposal options. CDFs are appropriate for consideration as a disposal option for dredged sediments of the Lower Fox River and Green Bay as long as the statutory restrictions for nearshore disposal can be accommodated. The disposal of contaminated sediments in landfills is considered an effective and implementable option for purposes of developing cleanup options for the Lower Fox River and Green Bay. However, under CERCLA, landfill disposal in addition to other disposal options mentioned above is not a preferred option primarily because the contaminated materials are merely relocated and the COCs are not destroyed.

6.5 Identification of Ancillary Technologies

Additional technologies and process options that are ancillary to the retained process options presented in Section 6.3 may be incorporated in the remedial alternatives. Incorporation of these technologies and process options is dependent on the process options chosen for a particular remedial alternative. For example, if removal and disposal in an off-site landfill is established as a remedial alternative, dewatering prior to transport of materials off site and subsequent treatment of the water generated in the process will take place.

Potential ancillary technologies and process options are not subject to the same screening process described in Section 6.2. However, they are presented here as considerations for the development of remedial alternatives provided in the following sections of this FS Report. A description of ancillary technologies that are a part of certain remedial alternatives are described in following subsections and include:

- Dewatering,
- Wastewater treatment,
- Residuals management and disposal,
- Transportation, and
- Water quality management.

6.5.1 Dewatering

Dewatering involves the removal of water from dredged sediment to produce a material more amenable to handling with general construction equipment and that meets landfill disposal criteria (e.g., paint filter test and compaction specifications). Selection of an appropriate dewatering technology depends on the physical characteristics of the material being dredged, the dredging method, and the target moisture level of the dewatered material. Dewatering technologies can be grouped into the following three categories:

- Mechanical dewatering,
- Passive dewatering, and
- Solidification.

Description of Dewatering Process Options

After removal, the dredged solids typically have moisture contents that must be reduced for effective treatment. Mechanically-dredged sediments typically have a solids content of approximately 50 percent by weight. Hydraulically-dredged sediments are in a slurry with a solids content typically in the range of 6 to 10 percent, with a maximum range of 10 to 12 percent (EPA, 1994a). Dewatering these sediments requires management of the contaminated water, which has direct cost implications.

Mechanical Dewatering. Mechanical dewatering equipment physically forces water out of sediment. Four techniques are typically considered for dewatering dredged sediments: centrifugation, diaphragm filter presses, belt presses, and hydrocyclones.

Centrifugation uses centrifugal force to separate liquids from solids. Water and solids are separated based upon density differences. The use of a cloth filter or the addition of flocculent chemicals assists in the separation of fine particles. Typical production rates of a single centrifuge vary from 20 to 500 gallons per minute (gpm). Assuming a dredged slurry solids content of 4 percent by volume and a dewatered solids content of 30 percent by volume, production rates vary from approximately 1 to 21 cy/hr. Centrifuges are suitable for areas along the Lower Fox River where larger dewatering systems (operations) are impractical. The process works well with oily sediments and can be used to thicken or dewater dredge slurries.

Hydrocyclones are continuously-operated devices that use centrifugal force to accelerate the settling rate of particles within water. Hydrocyclones are cone shaped. Slurries enter near the top and spin downward toward the point of the cone. The particles settle out through a drain in the bottom of the cone, while the effluent water exits through a pipe exiting the top of the cone. The production rate and minimum particle size separated are both dependent upon the diameter of the hydrocyclone. Generally, a wider hydrocyclone has a greater production rate, whereas narrower hydrocyclones are better at separating out smaller particles, albeit at lower throughput rates. The production rate of a single unit varies from 50 to 3,500 gpm, depending on equipment diameter. Assuming a dredged slurry solids content of 4 percent by volume and a dewatered solids content of 30 percent by volume, the production rates vary from approximately 2 to 150 cy/hr. Two hydrocyclones were used during the Deposit N demonstration project to remove +200 sieve material after removal of gravel-sized stones and debris.

Diaphragm filter presses are filter presses with an inflatable diaphragm, which adds an additional force to the filter cake prior to removal of the dewatered sediments from the filter. Filter presses operate as a series of vertical filters that filter the sediments from the dredge slurry as the slurry is pumped past the filters. Once the filter's surface is covered by sediments, the flow of the slurry is stopped and the caked sediments are removed from the filter. Filter presses are available in portable units similar to the centrifuge units. Although very costly and labor intensive, production rates for a single unit vary from 1,200 to 6,000 gpm. Assuming a dredged slurry solids content of 4 percent by volume and a dewatered solids content of 30 percent by volume, the production rates vary from approximately 50 to 250 cy/hr.

Belt presses use porous belts to compress sediments. Slurries are sandwiched between the belts, resulting in high-pressure compression and shear which promotes the separation. Flocculents are often used to assist the removal of water from the sediments. The overall dewatering process usually involves gravity-draining free water, low-pressure compression, and finally high-pressure compression. Belt presses can be fixed-based or transportable. They are commonly used in sludge management operations at municipal and industrial wastewater treatment plants throughout the Lower Fox River valley.

Belt press efficiencies are dependent upon belt speeds, tension, material composition, feed concentrations, and flocculent dosing. Typical production rates of a single unit vary from 40 to 100 gpm. Assuming a dredged slurry solids content of 4 percent by volume and a dewatered solids content of 30 percent by volume, the typical production rate varies from approximately 2 to 4 cy/hr. A type of belt press, called the recessed chamber filter press, was used for dewatering hydraulically-dredged sediments from Deposit N. The press was used after a gravity-settling stage and polymer conditioning to enhance filter performance. The filter cake produced was sufficiently dewatered for transport and disposal off site.

Passive Dewatering. Passive dewatering refers to gravity settling of solids. Passive dewatering can occur on sediment barges, within CDFs, and in specially built lagoons or ponds. The process requires sufficient retention time to allow sediment particles to settle, after which the clarified water may be discharged (or treated and then discharged depending on composition and discharge limitations). Passive dewatering is used for mechanical dredging of the Green Bay navigation channel by the Green Bay Port Authority. Passive dewatering was considered feasible for the SMU 56/57 demonstration project (Montgomery-Watson, 1998).

On-barge dewatering is typically used in conjunction with mechanical dredging. Sediment is deposited inside the dredge-barge and water is allowed to drain by gravity. Typical dredge-barges are equipped with side drains which allow the water to flow from the barge into the water body. Dredge-barges may also be configured with a floor that slopes to a collection sump for collection and treatment of the water before discharge to the water body.

Dewatering in large upland ponds is typically used in conjunction with hydraulic dredging. The dredged sediments are pumped to the pond and allowed to settle. Clarified water is decanted and thickened sediment is removed once the pond fills to a level that reduces settling performance. The addition of baffles to the settling pond increases the effective holding time and separation. Figure 6-6 illustrates the layout of a 4-acre dewatering pond. This type of facility is currently used at Bayport to manage sediments dredged from the Green Bay navigation channel.

An in-river passive dewatering facility may also be considered in the design phase, particularly for the De Pere to Green Bay Reach or Little Lake Butte des Morts. An in-water facility could be constructed using sheet piling and likely requiring about 20 acres of river bottom. Dredge slurry would be pumped into a two-cell (or more) facility, dewatered, then dry excavated with earthmoving equipment. An underlying clay layer or bedrock would be a natural effective liner and would not entail additional construction costs or maintenance. An in-water facility would eliminate the need and cost of locating an upland area.

If temporary passive dewatering ponds are used, the performance requirements of Chapter NR 213 ("Lining of Industrial Lagoons and Design of Storage Structures") may apply. Alternatively, if WDNR decides to regulate passive dewatering ponds as a "solid waste processing facility," the requirements of the NR 500 series of rules may apply.

Solidification. Solidification involves mixing a chemical agent with dredged sediments to absorb moisture. Portland cement, pozzolan fly ash, fly ash/Portland cement mixtures, and lime kiln dust are common additives. The chemical agent and sediments may be mixed in a pug mill or in a contained area (e.g., a roll-off box or pit) using an excavator, depending upon sediment production rates and work space areas. Solidification is commonly used for sediments that have been partially dewatered by another means. Mechanically-dredged sediments can sometimes be solidified directly. Solidification is not a practical method for dewatering hydraulically-dredged sediments in the absence of thickening the solids by some other means, as the amount of chemical agent required becomes cost prohibitive. For the purposes of this FS, it was assumed that passively dewatered sediment would require solidification with 10 percent (w/w) lime, based on data provided in the SMU 56/57 Basis of Design Report (Montgomery-Watson, 1998).

Screening Criteria for Dewatering

The principal criteria used to screen dewatering methods are the type of removal options selected for a given river reach and available land for construction and operation of a passive dewatering facility.

- **Hydraulic Dredging.** *A passive dewatering facility is selected for all hydraulic dredging options where there are greater than 10 to 15 acres of land available for construction and operation of the settling ponds.* At least one alternative will include mechanical dewatering to provide a comparison in costs.

- **Mechanical Dredging.** Passive on-barge dewatering is selected for all mechanical dredging options.

Additional operating parameters and constraints which must be considered in selecting the appropriate dewatering technique for the Lower Fox River include:

- **Production Rate.** The selected dewatering technique should produce dewatered sediments at a rate equivalent to the sediment removal rate. This allows sediment to be removed by the dredges without concern for sediment storage prior to dewatering.

- **Effectiveness.** The selected dewatering technique must be capable of consistently meeting specific the requirements for disposal. This requirement is at least 50 percent solids without the addition of any solidification agents.

- **Dewatering Barge Availability.** Dredge-barges with onboard water collection sumps are not locally available. Such a barge may need to be constructed locally.

- **Siting.** Placing a dewatering pond a significant distance from the river may be impractical from a material handling standpoint. It may also be impractical to remove a large wooded area to install a dewatering pond.

- **Discharge Water Quality.** All water removed from the dredged sediments must meet certain regulatory requirements prior to discharge to a publicly-owned treatment works (POTW) or to the river. The drain water from standard dredge-barges may not meet WPDES requirements to return to the Lower Fox River without further water treatment.

Screening Evaluation for Dewatering

Implementability. All three dewatering technologies discussed above are implementable for cleanup of sediments in the Lower Fox River and Green Bay. Space availability for settling basins along the Lower Fox River and Green Bay will be a key implementability consideration in the development and evaluation of remedial alternatives (Section 7).

Dredge-barges with onboard water collection sumps are not locally available and therefore may need to be constructed locally.

In all cases, the dewatering operation must be sized so that the production rate is compatible with the sediment removal (dredging) rate.

Effectiveness. The water removal technologies discussed here are commonly practiced and effective methods for dewatering sediments. For treatment or disposal, dewatering must be capable of generating a material of at least 50 percent solids without the addition of any solidification agents.

All water removed from the dredged sediments must meet certain regulatory requirements prior to discharge to a POTW or to the river. The drain water from standard dredge-barges may not meet WPDES requirements to return to the Lower Fox River without further water treatment.

Dewatering Costs

Dewatering costs depend upon the size of the pond, time allowed to settle, physical properties of the material, and disposal requirements. For the Fox River project, passive dewatering costs are relatively low compared to moderately-priced mechanical dewatering options. However, the costs for dewatering are usually inversely proportional to disposal costs.

Screening Decision

In this FS, passive dewatering in settling basins is assumed for dewatering hydraulically-dredged sediments. This dewatering method requires adequate upland or nearshore space (e.g., greater than 10 to 15 acres) for construction and operation of the settling basins. Passive on-barge dewatering is assumed for mechanical dredging options. Solidification may be useful during some elements of sediment remediation in the Lower Fox River and Green Bay, but is not central to the development of remedial alternatives in Section 7.

For the purposes of this FS, it was assumed that passive dewatering would occur in bermed areas lined with asphalt pavement to allow access by heavy equipment. Due to space limitations and a desire to maximize the settling time, the design storage depth is 8 feet, thereby limiting the land needed to approximately 10 acres for the Little Lake Butte des Morts and Appleton to Little Rapids reaches and 15 acres for the Little Rapids to De Pere Reach. It was further assumed that the dewatered solids content would be 35 percent after dewatering for a period of 3 to 6 months based on data provided in the SMU 56/57 Basis of Design Report (Montgomery-Watson, 1998). In order for the dewatered sediment to be handled and disposed, it was assumed that solidification using 10 percent lime was also necessary.

6.5.2 Wastewater Treatment

Water from the dredged sediment dewatering operation must be treated to meet effluent water quality criteria for discharge to the receiving system. The receiving system may be a permitted discharge to the river or bay, a POTW, or an industrial wastewater facility. Water quality may be adversely impacted in and around dredging operations through resuspension and dispersion of contaminated sediments. Therefore, controls on suspended solids are an important consideration in the development of remedial alternatives involving sediment removal. These were discussed with respect to the effectiveness of dredging (Section 6.4.2). Water quality is also an issue in dewatering operations where produced water may require treatment to meet discharge standards.

Water Treatment

Mechanical Dredge Water Treatment. Free water derived from mechanical dredging is principally within the transfer barges, or at the consolidation (stockpile) facility. Dredged sediment transfer barges are left idle before off-loading to allow for collection of free water at the surface of the load by sediment self-consolidation. The free water can then be decanted and pumped ashore to a water treatment system, if necessary, before unloading the dredged material. An onshore water treatment system may consist of one or several Baker tanks for primary sedimentation of solids, coagulant-aided secondary flocculent settling of remaining suspended solids, and filtration (i.e., sand, mixed media, activated carbon), if needed, to meet water quality requirements.

Shoreside stockpile areas can be graded, bermed, and lined to contain and collect sediment drainage and rainfall runoff. Once sufficiently dewatered, stockpiled material may be treated on site, or loaded onto trucks or rail cars for transport to the treatment or disposal facility.

Water treatment may be required to meet water quality requirements for discharge back to the river. At a minimum, treatment would involve gravity sedimentation and possibly filtration for solids removal. The disposal cell could be designed with a compartment for quiescent settling with or without coagulant addition. Free water present at the surface of the haul barge would be pumped ashore to the disposal cell/water treatment system before off-loading in order to minimize tendency for washout/spillage during the off-load swing. More involved treatment, depending on discharge criteria, could involve the use of standard process options such as:

- Coagulation, flocculation, and settling;
- Filtration (i.e., sand, mixed media);

- Adsorption using granular activated carbon; and
- Ozone, UV/ozone, or UV/peroxide oxidation.

Alternatively, gravity-separated water could be directly discharged to a POTW. The discharge of water to a POTW depends on meeting certain discharge criteria as set by the municipality. In the past, WDNR has authorized a minimum dilution zone for dredge water return flow. For the purposes of this FS Report, it is assumed that acute water quality criteria must be met at the point of discharge and a mixing zone or zone of initial dilution is allowed to satisfy chronic criteria.

Hydraulic Dredge Water Treatment. Hydraulic dredging results in a large volume of sediment-water slurry to be managed. Flow rates in small dredges can range from as little as 900 gpm (80 cy/hr) for a 6-inch dredge, to more than 4,000 gpm (354 cy/hr) for a 14-inch dredge. Hydraulic dredging rates in contaminated sediment removal are frequently limited by the capacity and treatment rates of the water quality system.

Conventional separation of solids from the dredged slurry occurs by gravity sedimentation in a suitably-sized, quiescent retention pond. The return flow is decanted over a weir to skim the clarified water from the surface in order to meet water quality requirements before discharge.

Other means of solids removal for hydraulic dredging have been tested (EPA, 1994a; SEDTEC, 1997). In 1995 through 1996, approximately 100,000 cy of hydraulically-dredged contaminated sediment was dewatered by adding a coagulant aid to the slurry stream and routing the flow through a set of two clarifiers for thickening and then through belt presses for landfilling (Ohio River Dredge and Dock, Inc.). A proprietary process (Solomon Venture, Lakewood, Colorado) reports success in using a system of screens and grids to remove particles down to 1-micron size at dredge flows of 1,200 gpm. An emerging solids separation technology uses geomembrane tubes designed to pass water, but not selected sediment sizes. Sandy sediments have been pumped into such tubes for separation of solids. However, the membranes may be subject to blinding (plugging) for high concentrations of fine-grained materials.

Given the physical limitations on ponding cell sizes, it is likely that the hydraulic dredge used for the Lower Fox River in Little Lake Butte des Morts and between Little Rapids and De Pere would be limited to the small dredge sizes: 6 to 10 inches.

Ponding cells would be sized to at least provide the required hydraulic retention capacity. However, the minimum cell size would also need to be balanced with the sediment storage capacity required for deposition of the affected fractions of dredged materials. For Lower Fox River sediment removal, the requirement for cell storage capacity for sediment deposition would dominate the primary cell sizing. A properly designed coagulant-aided solids separation system would be expected to produce return flow effluent with less than 200 mg/L total suspended solids.

An alternative would be a constructed gravity thickener, or clarifier, in place of the above secondary settling cell. As the flocculated sediment settles toward the bottom of the clarifier, the thickened underflow would be collected and pumped to a mechanical filtration system (i.e., belt press) to produce a dewatered solids cake. The withdrawn water is cycled back to the clarifier inflow. Clarifier overflow water (i.e., the clarified dredge flow) is discharged back to the waterway, after meeting water quality requirements. Additional treatment of the effluent may be needed for water quality compliance, and might include sand, mixed media, and/or activated carbon filtration. If needed, such end-stage treatment will be expensive and may result in selecting an alternate dredging/disposal method.

An alternative to gravity sedimentation would be to import or construct a mechanical filtration system on site. Proprietary commercial installations have reported success in solids removal and dewatering the full slurry stream from a small hydraulic dredge (i.e., Solomon Liquids, Lakewood, Colorado; Global Dewatering, Edmonton, Canada.). Such systems can be utilized in tandem to increase overall flow capacity, if needed, for a project of this size (2,000 gpm). A typical system utilizes screens and centrifuges for solids removal, in some cases aided by chemical coagulants and short-term gravity separation. A properly designed and operated system would be expected to produce a return flow with less than 200 mg/L total suspended solids.

A multi-cell settling/treatment pond would allow addition of a coagulating agent to assist in secondary (final) sedimentation before discharge (USACE, 1987). The primary (first) cell would settle and retain the coarser-grained sediment within the first few hours of retention. The overlying suspended fine-grained supernatant would be discharged to the secondary settling cell after mixing with a chemical coagulant to aid in flocculent settling. Addition of the coagulating agent would be mixed by turbulence within the gravity flow discharge pipe(s) from the primary cell into the secondary cell, or a static mixing tank could be added between the cells if the gravity flow energy was not sufficient to result in proper mixing. Final design of the system would require additional testing to identify an optimum coagulant and concentration.

Other Wastewater Treatment Options

- **Off-site Commercial Treatment.** POTWs can be used for the treatment of effluent water from dredged sediments. This management option allows for the disposal of effluent waters. The discharge of water to a POTW is often dependent upon meeting certain discharge criteria as set by the municipality. This management method may be used in remedial alternatives where sediment dewatering is required.

- **Off-site Disposal of Hazardous Wastes.** Dredged material would be removed from dewatering cells as dewatered solids or filter cake by a rubber-tired front-end loader and loaded to screened refuse containers for transport to a treatment or disposal facility.

- **On-site Treatment of Organic Compound.** Carbon filtration and UV oxidation are commonly used management methods to remove organic compounds from effluent water. Treatment of organic compounds, depending upon concentrations, may be required to discharge effluent water to either a POTW or to the Lower Fox River under a WPDES permit. This management method may be used in remedial alternatives where sediment dewatering is required.

- **On-site Treatment of Suspended Solids and Metals.** Precipitation and froth tanks are commonly used management methods used to remove suspended solids and metals from effluent water. Treatment of suspended solids and metals, depending upon concentrations, may be required to discharge effluent water to either a POTW or the Lower Fox River under a WPDES permit. This management method may be used in remedial alternatives where sediment dewatering is required.

6.5.3 Residuals Management and Disposal

Residual management methods will be required for each remedial alternative. Residual management will vary depending upon the chosen remedial alternative. The following provides a description of each of the residual management methods including a summary of the applicability of these methods:

- **Off-site Disposal of Non-Hazardous Wastes.** Wastes such as personal protective equipment (PPE), filtration filters, and construction debris that is not characterized hazardous waste can be disposed of at a local municipal landfill. This management method will be used in all remedial alternatives. The quantity generated will depend upon the remedial alternative.

- **On-site Beneficial Use.** Dewatered and treated sediments may be suitable as soil/sediment construction fill or placed in newly-constructed CDFs as dikes or retaining walls. The feasibility of these disposal techniques depends upon the physical properties of the material, residual concentrations, local needs, and jurisdiction rulings.

No screening evaluation is necessary for residuals management and disposal process options.

6.5.4 Transportation

Transportation methods will be needed for any remedial alternative which involves removal of the contaminated sediments. The transportation methods included in each remedial alternative will be based upon the compatibility of that transportation method to the other process options. The following provides a description of each of the transportation methods including a summary of the compatibility of these methods:

- **Truck.** Transport of dewatered sediment over public roadways using dump trucks, roll-off boxes, or trailers. Includes associated loading facilities. This technology applies to transport for short distances, and will be used in remedial alternatives where dewatered sediment is transported to an in-state landfill.

- **Rail.** Transport of dewatered sediment by railroad using open gondolas. Includes associated loading facilities. This technology applies to transport over long distances (greater than 300 miles), and will be used in remedial alternatives where the dewatered sediment is transported to an out-of-state landfill.

- **Barge.** Transport of high-solids sediment through existing navigable waterways using barges. Includes associated unloading facilities on the river shoreline. This technology applies to transport on the river in segments between dams or locks, and will be used in remedial alternatives where sediment removal is conducted using a mechanical dredge.

- **Pipeline.** Transport of low-solids sediment through pipelines directly from dredge equipment to a receiving point on the river shoreline, or to an off-site location using conventional transport. This technology applies to transport on the river and can be conducted along a river segment, or over a dam. Pipeline transport will be used in remedial alternatives where sediment removal is conducted using a hydraulic dredge.

No screening evaluation is necessary for transportation.

6.5.5 Water Quality Management

All removal technologies may increase the suspended solid load of the overlying waters, but vary in their overall impact. Solids loss or resuspension may or may not be significant in terms of environmental impact on the water column. In general, environmental impact is related to the magnitude of losses. However, the impact of low losses from environmental dredging are likely to have minimal impact on the waterway (Appendix B). There are operational controls that can further reduce the impacts to water quality during dredging. For selection of the final removal technology(ies), these points must be considered for both environmental protectiveness and cost.

Dredge Operator

Water quality impacts can be controlled by the careful selection of dredging equipment as well as using specific operation and technical controls. These can include skilled operators working the dredging units at slower rates, careful placement of the dredging equipment, and use of sediment curtains or booms to control spread of suspended solids.

Field assessments have shown that sediment resuspension by hydraulic dredge can be minimized by careful operation of the dredge (USACE, 1990). This involves controlling the speed of cutterhead rotation, the swing speed, the rate of dredge advance, and depth of cut. Recommendations for minimizing sediment resuspension at the dredge head include maintaining a slow to moderate cutter rotational speed at 15 to 20 rpm, a slow swing speed of 0.3 to 0.5 ft/s, and limiting the minimum cut depth to the range of 50 to 100 percent of the suction pipe diameter.

Containment Barriers

Water quality impacts from sediment resuspension at the dredge can also be reduced by conducting the dredging within a silt curtain, silt screen, or sheet piling enclosure in order to contain migration of the suspended solids or turbidity plume. The silt curtain is generally constructed of impermeable fabric and is suspended from the surface to the river bottom where it is anchored. The silt curtain can extend completely to the bottom with appropriate fringe weights and anchors. Gravity settling of the denser sediment plume and loose re-settled solids will seek the lowest point, resulting in some migration beneath the silt curtain. Experience elsewhere indicates more than 90 percent reduction in suspended concentrations across the silt curtain can be achieved under favorable conditions. Silt curtains are not effective in current speeds above approximately 0.5 ft/s or in high winds or waves (EPA, 1994a).

In comparison, the silt screen is constructed of permeable fabric designed to pass water, but not fine-grained resuspended sediment. Either the silt curtain or screen must be placed, managed, and removed with care to avoid resuspension and release of contaminated sediment during operations. Silt curtains and screen placement and operation may be a source of resuspension of bed sediment due to dragging or alteration of local currents. The need for and benefit of containment systems during dredging must be weighed against the utility of and potential disadvantages of these systems.

Sheet piling may be selected when site conditions such as stray currents, high winds, changing water levels, excessive ship traffic and wave height, or drifting ice and debris preclude use of silt curtains/screens. Sheet piles are generally constructed of impermeable, interlocking steel plates that are driven below mudline into an underlying clay layer. If bedrock underlies the dredge prism, then piles can be connected to the bedrock using driving pins. Sheet piles can be expensive to install, difficult to remove without disturbing neighboring structures, and may be most practical in areas where "excessive" resuspension is expected.

6.6 Monitoring

Monitoring is a key control and assessment technology for sediment remediation. Numerous guidance documents confirm the necessity for monitoring to measure the effectiveness, stability, and integrity of source control measures, and to verify achievement of project RAOs (EPA, 1998a, 1994a; Krantzberg *et al.*, 1999). For contaminated sediment projects, monitoring can be grouped into five categories:

- Baseline monitoring,
- Short-term monitoring during implementation,
- Verification monitoring immediately following an action,
- Long-term operation and maintenance monitoring of storage sites, and
- Long-term performance monitoring to determine whether RAOs are attained.

6.6.1 Baseline Monitoring

Baseline monitoring establishes a statistical basis for comparing conditions before and after the cleanup action. The RI for the Lower Fox River and Green Bay presents a large body of data on the site. However, the database consists of information derived from numerous investigations that utilized varying methodologies. Further, the investigations cover a considerable time frame. Before implementing a specific cleanup action, baseline sampling and analysis of sediment and tissue samples will be required. The sampling design will be sufficiently rigorous to allow statistical comparison of conditions before, during, and following the cleanup action.

6.6.2 Implementation Monitoring

Short-term monitoring during remediation is used to evaluate whether the project is being implemented in accordance with specifications (i.e., performance of contractor, equipment, barriers, environmental controls). For removal or capping operations, short-term monitoring evaluates water quality near operations to determine whether contaminant resuspension and downgradient movement is being adequately controlled (e.g., with silt curtains). Water quality monitoring generally consists of surface water samples and frequent turbidity measurements. As demonstrated in the Deposit N pilot project, a PCB mass balance approach can be an effective method for tracking PCB mass management and loss through every phase. Bathymetric monitoring evaluates whether target sediments are being removed in dredging operations, or whether cap materials are being placed in the design location and at the design thickness. Bathymetry surveys are generally required during dredging operations to track removal progress and payment terms for contractors. Poling surveys are often used to ground-truth the bathymetry measurements. Other process monitoring may also be required depending on the remedial alternative. For example, sediment removal rates and slurry percent solids are important parameters to measure during hydraulic dredging operations.

6.6.3 Verification Monitoring

Verification monitoring evaluates post-removal surface and subsurface sediment conditions in dredging areas to confirm compliance with project specifications.

6.6.4 Operation and Maintenance Monitoring

Long-term maintenance monitoring of containment and/or disposal sites (i.e., nearshore fills, CAD sites, conventional *in-situ* caps) will be required to ensure adequate source control and continued stability of the structure. These O&M costs are included in the disposal (or containment) construction costs. The monitoring program will likely include surface and subsurface sediment and water quality monitoring, but the scope will be finalized during the remedial design phase.

6.6.5 Long-term Monitoring

Long-term monitoring evaluates sediment and tissue quality at the site for an extended period following the remedial action. In addition, disposal facilities are monitored for structural integrity and to ensure that the COCs continue to be contained. The scope of the former component of long-term monitoring (i.e., sediment and tissue sampling) is largely independent of the specific remedial action, although sampling locations and frequency can vary. The scope of the latter component depends on the location, type, and configuration of the disposal facility. A comprehensive *Long-term Monitoring Plan* for sediment and tissue quality for the Lower Fox River and Green Bay is detailed in Appendix C. Facility-specific monitoring is discussed in the context of remedial alternatives developed in Section 7.

No screening evaluation is necessary for monitoring options.

6.7 Section 6 Figures and Tables

Figures and tables for Section 6 follow page 6-74 and include:

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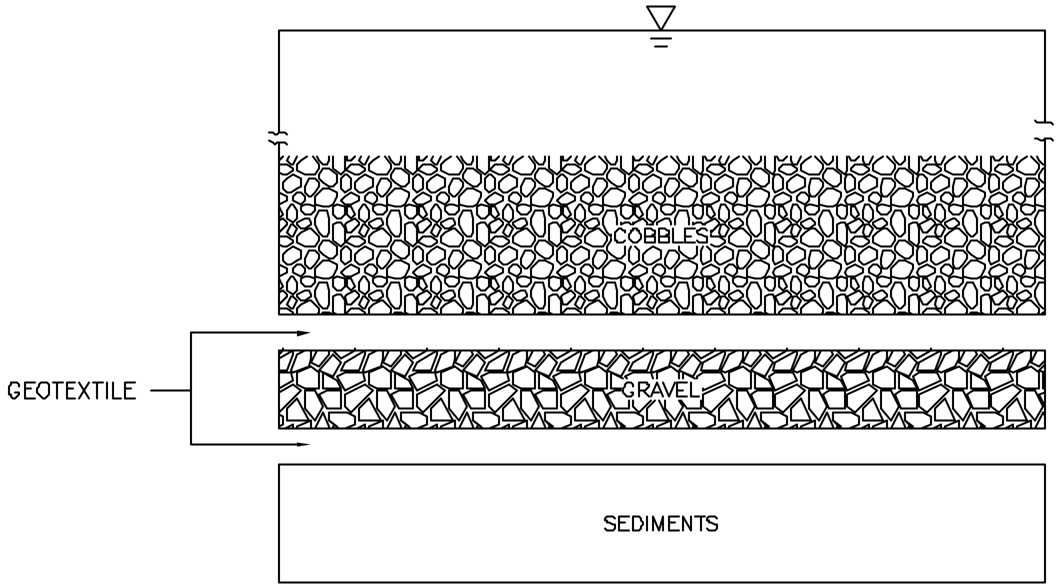
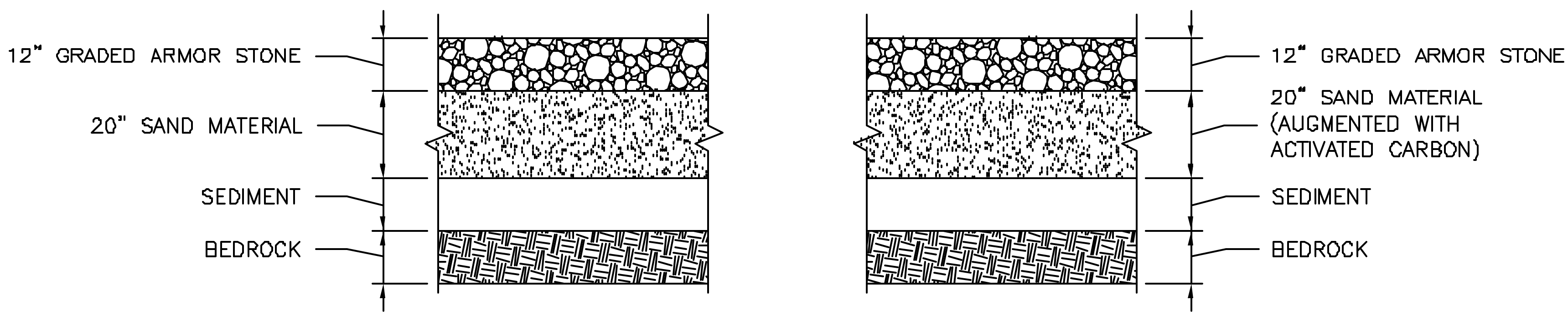


SHEBOYGAN FALLS, WI



MANISTIQUE HARBOR, MI

ThermoRetec

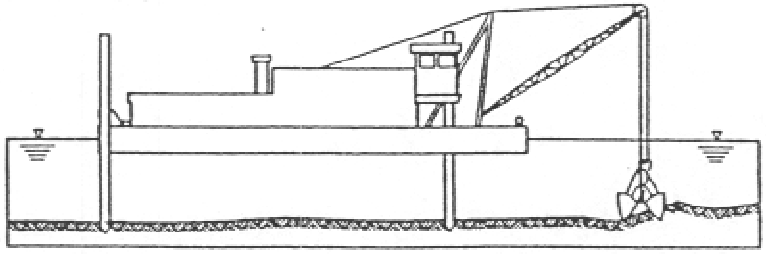
LOWER FOX RIVER
FEASIBILITY STUDY
WISCN-14414-535

EXAMPLES OF ARMORED CAPS

DATE: 09/15/00 | DRWN: N.S. | FILE: 14414G001

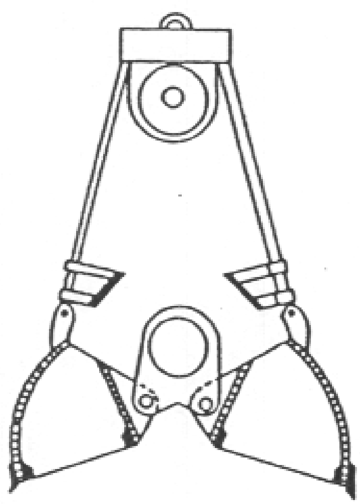
FIGURE 6-1

Mechanical dredge



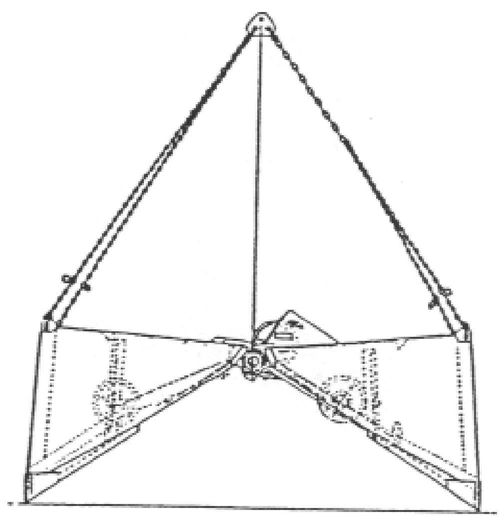
Source: USACE/USEPA (1992)

Enclosed Bucket



Source: Herbich and Brahme (1991).

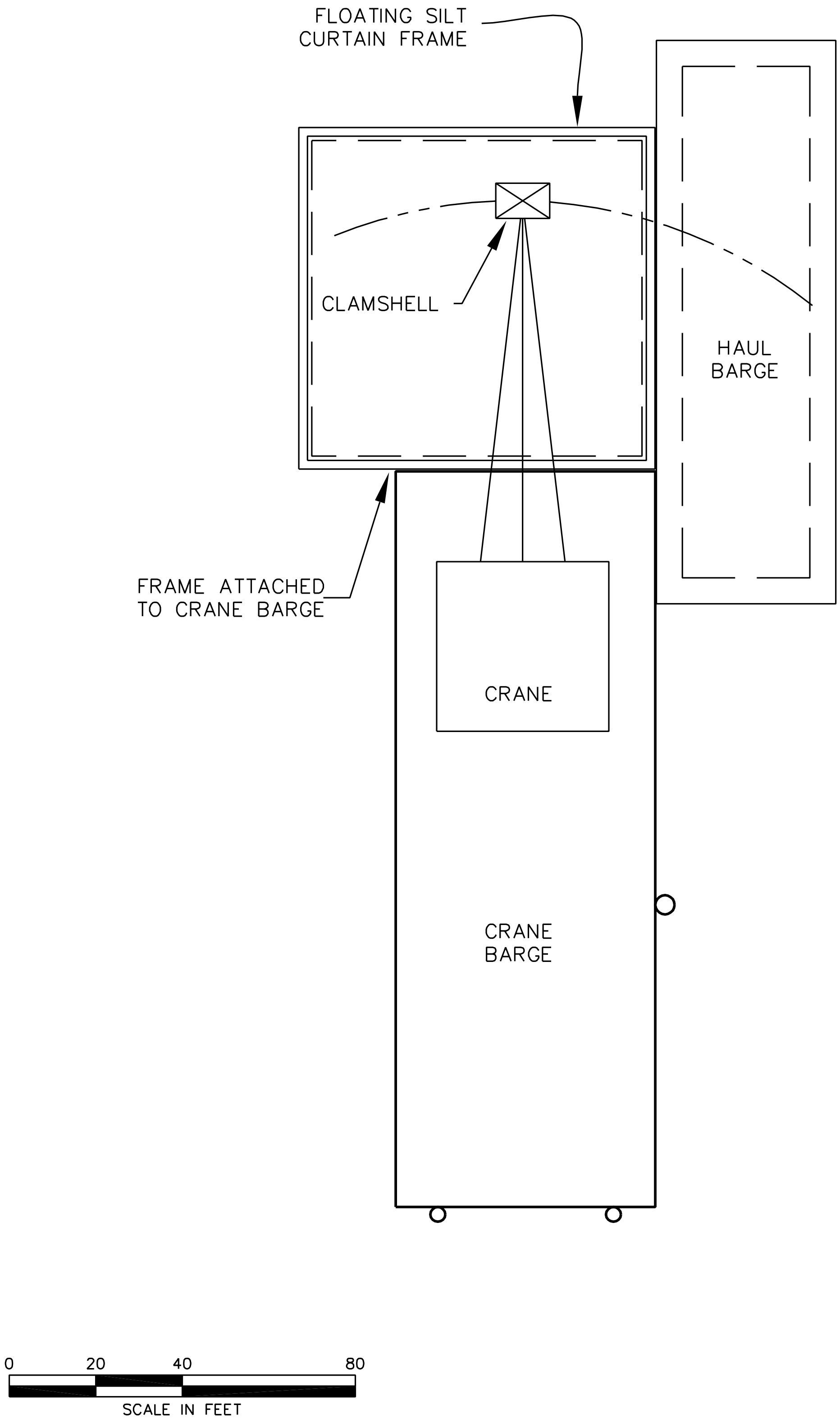
Cable Arm Bucket



Source: Cable Arm, Inc.

ThermoRetec

LOWER FOX RIVER FEASIBILITY STUDY 3-3584-900	EXAMPLES OF MECHANICAL DREDGES
CURRENT DATE 01-13-99 CADD FILE	FIGURE 6-2



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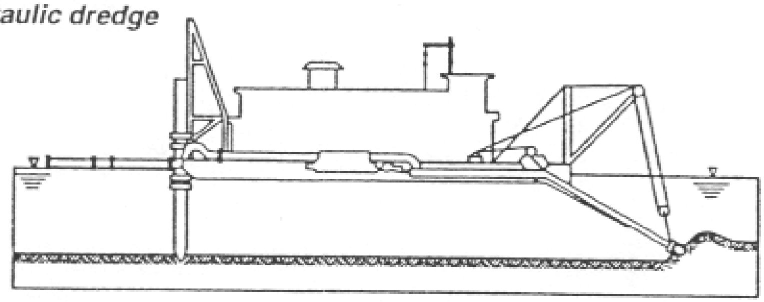
LOWER FOX RIVER
FEASIBILITY STUDY
WISCN-14414-535

TYPICAL MECHANICAL DREDGE OPERATIONS

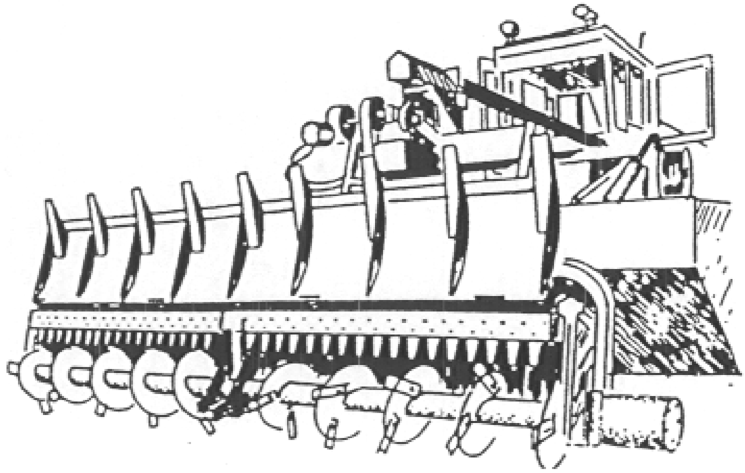
DATE: 07/12/01 | DRWN: N.S. | FILE: 14414D004

FIGURE 6-3

Hydraulic dredge

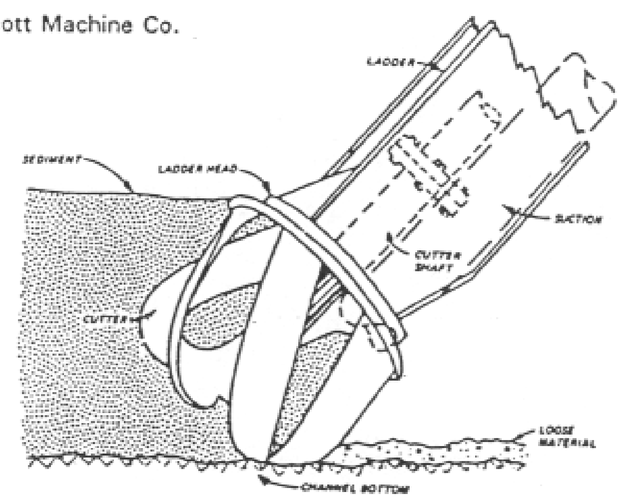


Source: USACE/USEPA (1992)



Horizontal Auger Dredge

Source: Ellicott Machine Co.



Conventional (Open Basket) Dredgehead

Source: Zappi and Hayes (1991)

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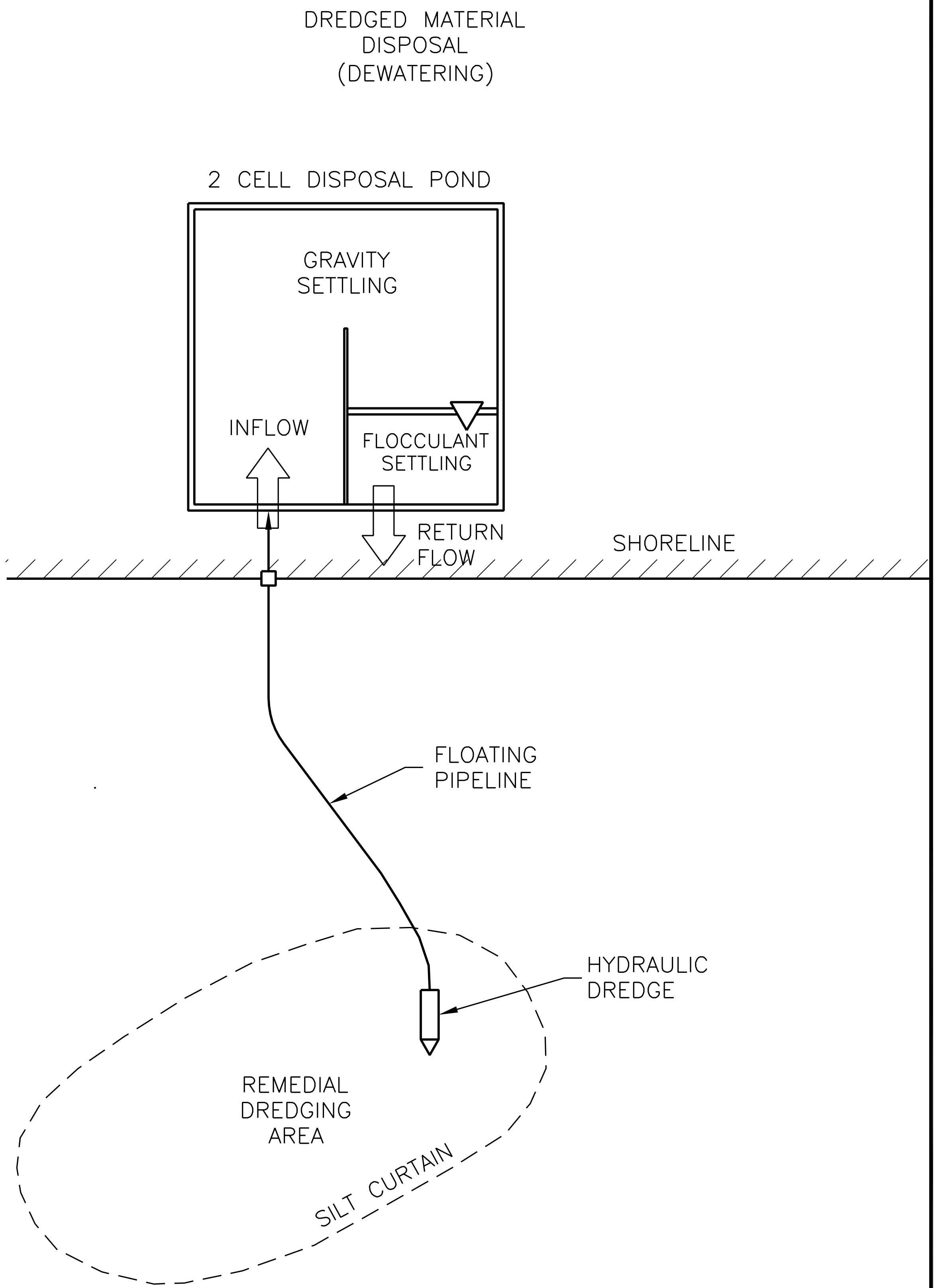
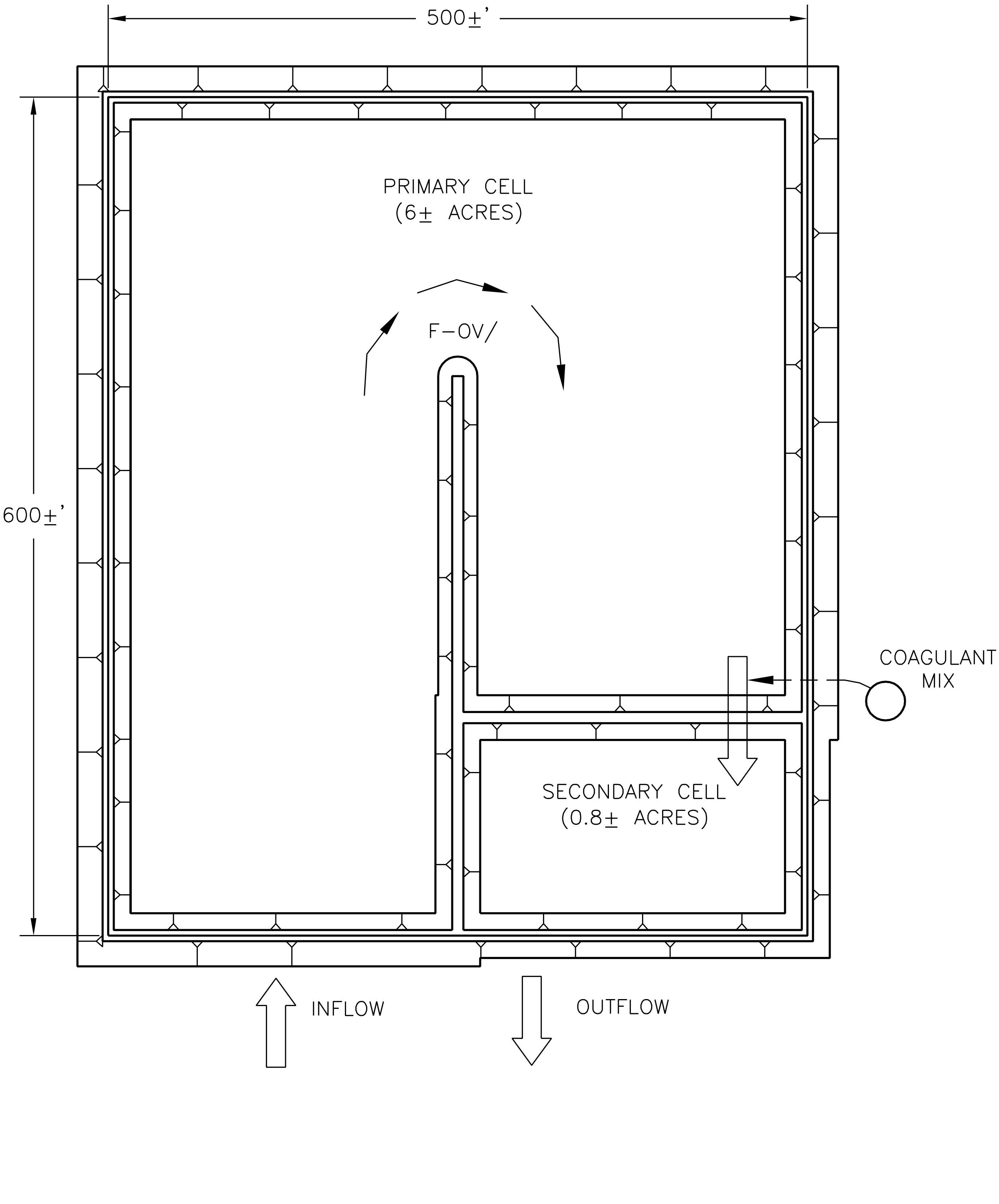
LOWER FOX RIVER FEASIBILITY STUDY 3-3584-900	EXAMPLES OF HYDRAULIC DREDGES
CURRENT DATE 01-13-99 CADD FILE	FIGURE 6-4



ThermoRetec	LOWER FOX RIVER FEASIBILITY STUDY WISCN-14414-535	**CONCEPTUAL HYDRAULIC DREDGING TO DEWATERING POND**
	DATE: 07/12/01 DRWN: N.S. FILE: 14414D003	**FIGURE 6-5**



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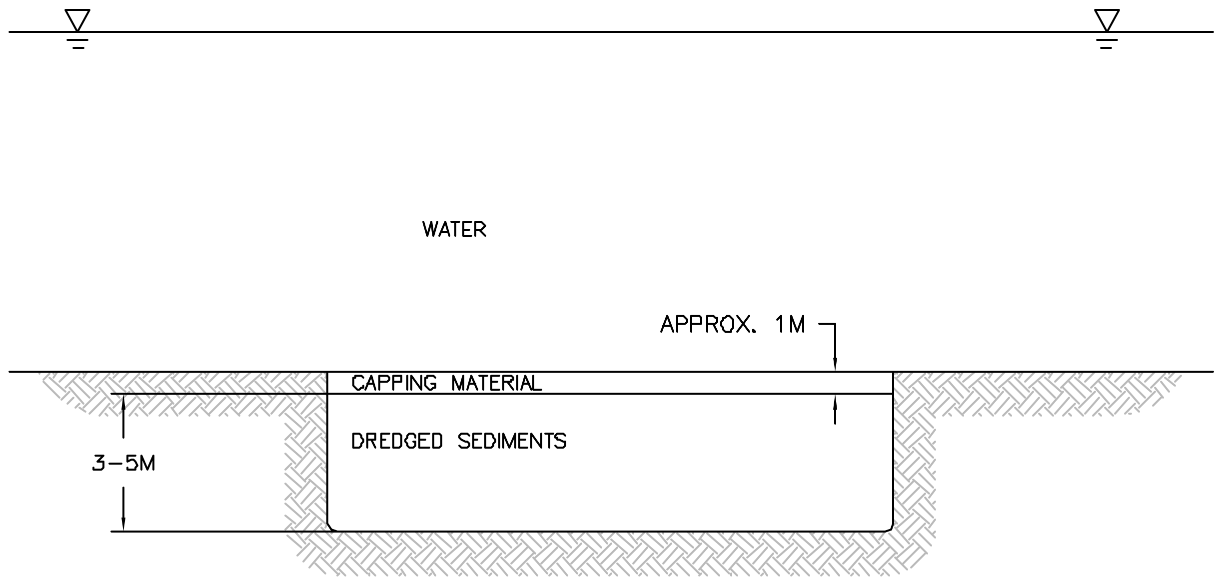
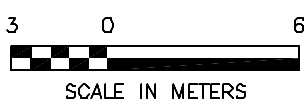
LOWER FOX RIVER
FEASIBILITY STUDY
WISCN-14414-535

CONCEPTUAL LAYOUT OF A GRAVITY DEWATERING POND

DATE: 07/12/01	DRWN: N.S.	FILE: 14414D005	**FIGURE 6-6**





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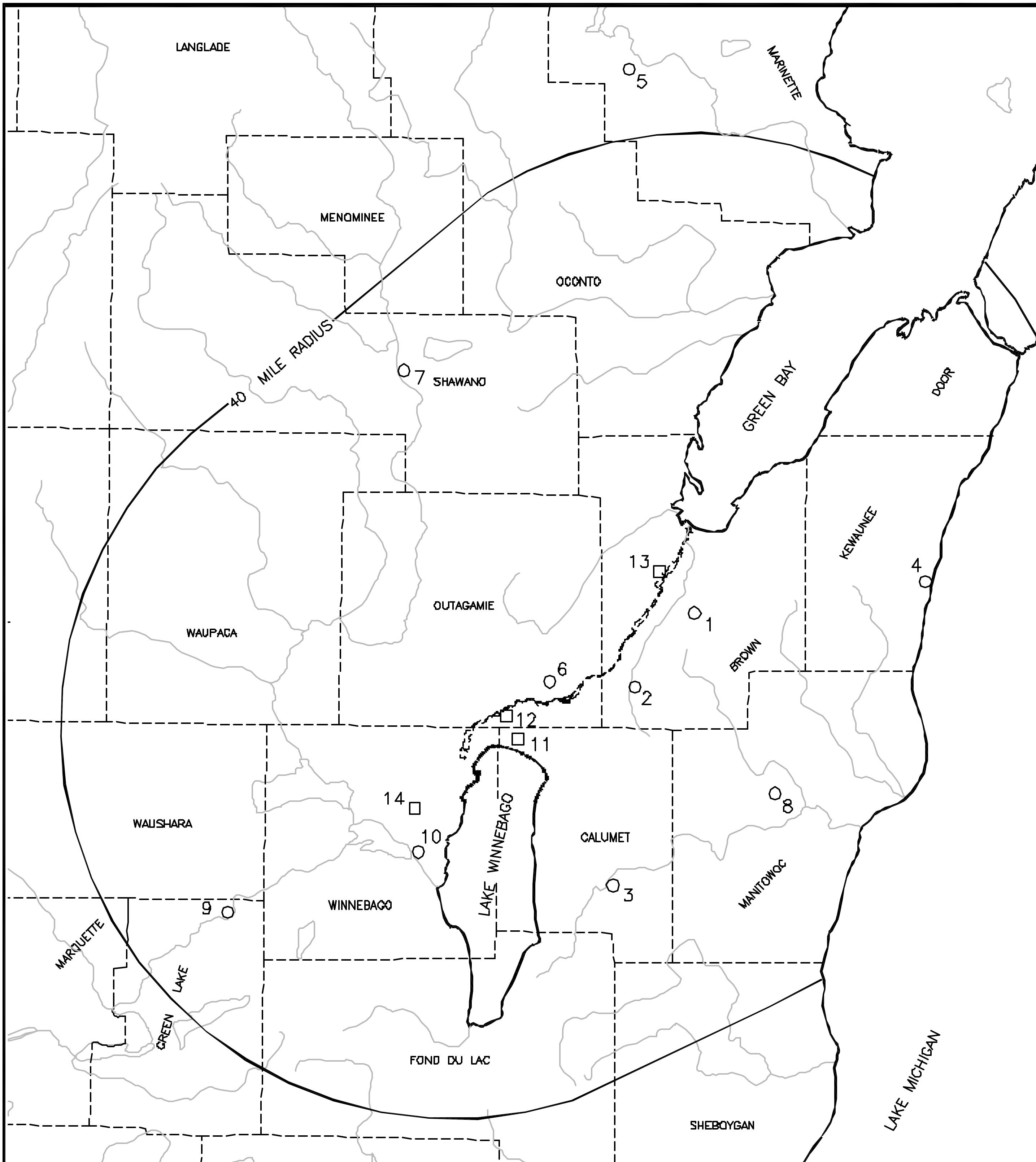
LOWER FOX RIVER
FEASIBILITY STUDY

WISCN-14414-535

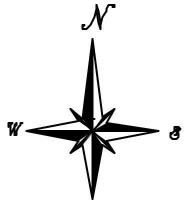
DATE: 04/19/01 | DRWN: S.E. | FILE: 14414G002

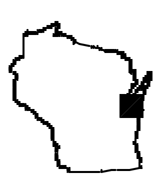
CROSS-SECTION OF CONFINED AQUATIC DISPOSAL

FIGURE 6-7



LOWER FOX RIVER GENERAL LANDFILL LOCATION MAP





3500' 0 7000'

SCALE 1"=7000'

LEGEND

○ 21 GENERAL LOCATION MUNICIPAL LANDFILL

□ 15 GENERAL LOCATION NON MUNICIPAL LANDFILL

(NUMBERS CORRESPOND TO LANDFILLS LISTED ON TABLE 6-17 OF FEASIBILITY STUDY)

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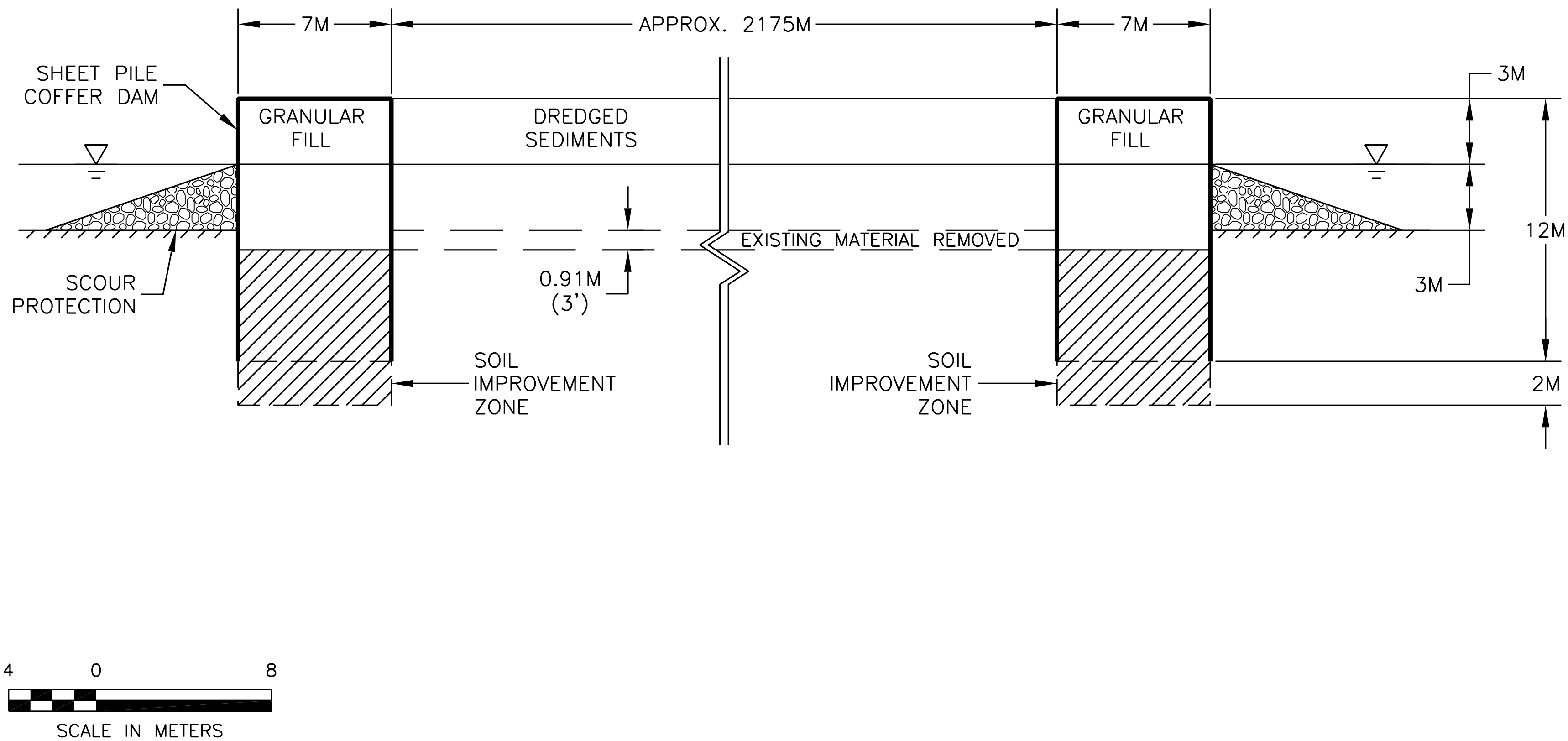
LOWER FOX RIVER FEASIBILITY STUDY WISCN-14414-535	GENERAL LANDFILL LOCATION MAP

CURRENT DATE	04/19/01	CADD FILE	14414s019		FIGURE 6-8



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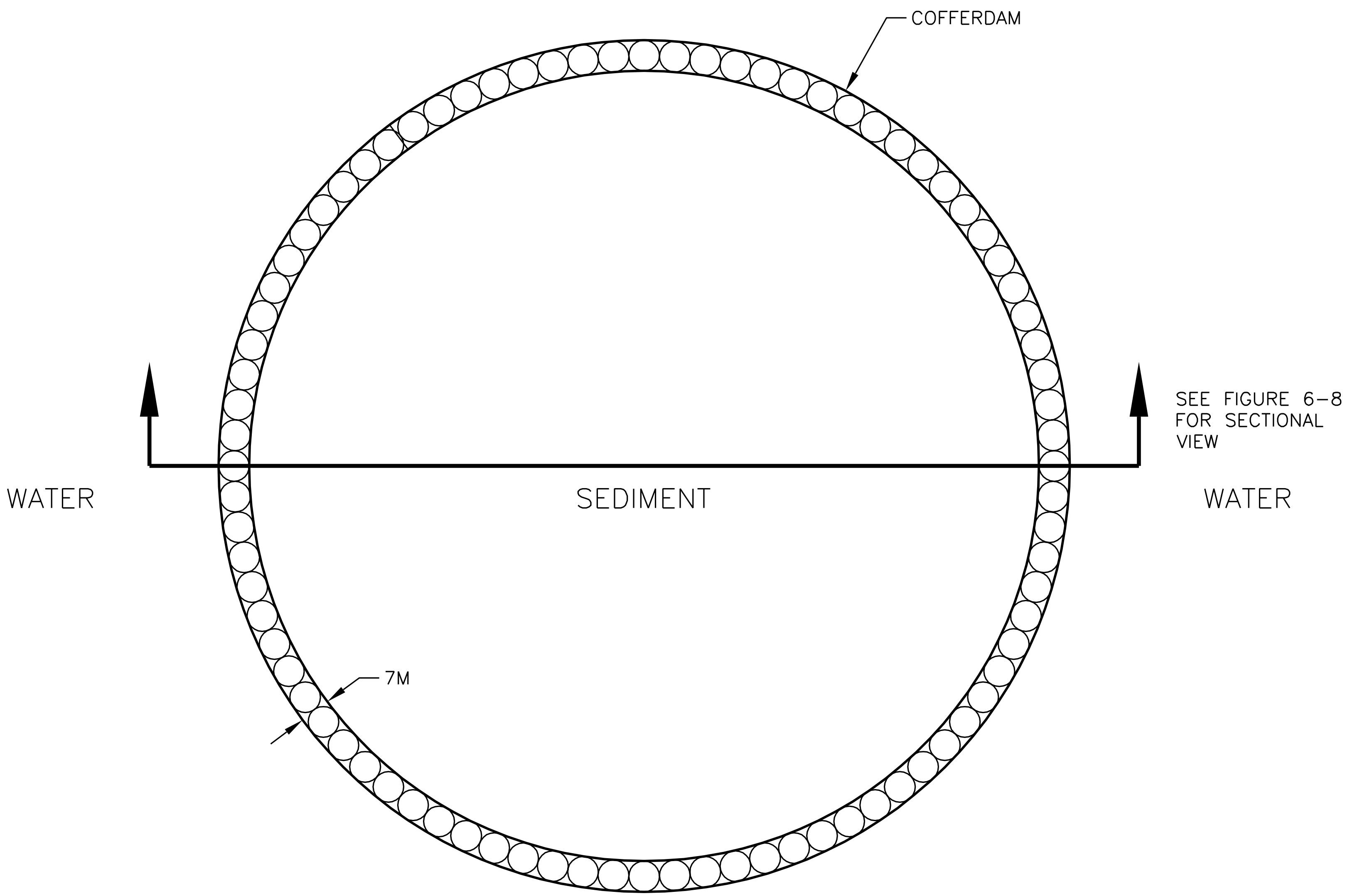
LOWER FOX RIVER
FEASIBILITY STUDY
WISCN-14414-535

DATE: 07/26/00 | DRWN: N.S. | FILE: 14414D001

CROSS-SECTION OF CELLULAR COFFERDAM CDF

FIGURE 6-9



NOT TO SCALE

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LOWER FOX RIVER
FEASIBILITY STUDY
WISCN-14414-535

PLAN VIEW OF WASTE
CELLULAR COFFERDAM CDF

DATE: 07/12/01 | DRWN: N.S. | FILE: 14414D002

FIGURE 6-10

Table 6-1 Guidance and Literature Resources Used to Develop the List of Potentially Applicable Technologies for Cleanup of the Lower Fox River and Green Bay

- *Remediation Technologies Screening Matrix and Reference Guide, Second Edition* (DOD, 1994)
- *Assessment and Remediation of Contaminated Sediments (ARCS) Program, Final Summary Report* (EPA, 1994a)
- *Assessment and Remediation of Contaminated Sediments (ARCS) Program, Remediation Guidance Document* (EPA, 1994a)
- *Review of Removal, Containment and Treatment Technologies for Remediation of Contaminated Sediment in the Great Lakes* (Averett *et al.*, 1990)
- *Dredging, Remediation, and Containment of Contaminated Sediments* (Demars *et al.*, 1995)
- *SEDTEC: A Directory of Contaminated Sediment Removal and Treatment Technologies* (SEDTEC, 1997)
- *Record of Decision, Sheboygan River and Harbor, Sheboygan, Wisconsin* (EPA, 2000a)
- *Remedial Investigation Report for Contaminated Sediment Deposits on the Fox River: Little Lake Butte des Morts to the De Pere Dam* (GAS/SAIC, 1996)
- *Feasibility Study Report for Deposits POG and N on the Fox River* (GAS/SAIC, 1997)
- *Remedial Investigation/Feasibility Study - Little Lake Butte des Morts - Sediment Deposit A* (Blasland & Bouck Engineers, P.C., 1993)
- *Engineering Evaluation/Cost Analysis: Manistique River and Harbor* (BBL, 1994)
- *Sheboygan River and Harbor Feasibility Study* (BBL, 1998)
- *Feasibility Study Report - Deposit A Little Lake Butte des Morts* (EWI Engineering Associates, Inc., 1992)
- Dredging Dallas' White Rock Lake in *World Dredging Mining and Construction,* April 1998. Describing a 20-mile-long slurry pipe run to disposal site (Sosnin, 1998).

Table 6-2 Summary of Technologies Reviewed and Retained[3]

General Response Action	Remedial Technology	Process Option
No Action	None	Not Applicable
Institutional Controls	Physical, Engineering or Legislative Restrictions	Consumption Advisories Access Restriction Dredging Moratorium
Monitored Natural Recovery	Physical Degradation	Combination of Desorption, Diffusion, Dilution, Volatilization, Resuspension, and Transport
	Biological Degradation	Dechlorination (aerobic and anaerobic)
	Physical Burial	Sedimentation
Containment	Capping	Conventional Sand Cap Sediment Clay Cap Armored Cap Composite Cap Thin-layer Cap Enhanced Cap
	Rechannelization	Construct New Channels
Removal	Dredging	Hydraulic Dredging Mechanical Dredging
	Dry Excavation	Excavator (for specific conditions)
In-situ Treatment	Biological	*In-situ* Slurry Biodegradation *In-situ* Aerobic Biodegradation *In-situ* Anaerobic Biodegradation
	Chemical	*In-situ* Slurry Oxidation Aqua MecTool™ Oxidation *In-situ* Oxidation Electrochemical Oxidation
	Physical Extractive Processes	Sediment Flushing SVE/Thermally Enhanced SVE/Bioventing Air Sparging
	Physical-Immobilization	Air Sparging MecTool™ Stabilization Vitrification Imbiber Beads™ Ground Freezing

[3] **Note:** Shading designates technologies that were retained in developing remedial alternatives.

Table 6-2 Summary of Technologies Reviewed and Retained (Continued) [3]

General Response Action	Remedial Technology	Process Option
Ex-situ Treatment	Biological	Landfarming/Composting Biopiler Fungal Biodegradation Slurry-phase Biological Treatment Enhanced Biodegradation
	Chemical	Acid Extraction Solvent Extraction Slurry Oxidation Reduction/Oxidation
	Chemical/Physical	Dehalogenation Sediment Washing Radiolytic Dechlorination
	Physical	Separation Solar Detoxification Solidification
	Thermal	Incineration High-temperature Thermal Desorption Low-temperature Thermal Desorption Pyrolysis Thermal Destruction Vitrification High-pressure Oxidation
Disposal	On Site	Level Bottom Cap Confined Aquatic Disposal (CAD) Confined Disposal Facility (CDF) Nearshore Biofiltration Cell Upland Confined Fill
	Off Site	Existing Upland Landfill Dedicated New Landfill TSCA Landfill Upland Confined Fill (commercial) Upland Fill (residential)

[3] **Note:** Shading designates technologies that were retained in developing remedial alternatives.

Table 6-3 Description of Potential Remedial Technologies

GRA	Technology	Process Option	Description
No Action	*None*	Not Applicable	No active remedy (i.e., passive remediation by natural processes).
Institutional Controls	*Physical, Engineering, or Legislative Restrictions*	Consumption Advisories	Advisories to indicate that consumption of fish in the area may present a health risk.
		Access Restrictions	Constraints, such as fencing and signs, placed on property access.
		Dredging Moratorium	Restricts dredging operations.
Monitored Natural Recovery	*Physical Degradation*	Combination	Desorption, diffusion, dilution, volatilization, resuspension, and transport.
	Biological - Degradation	Dechlorination (aerobic and anaerobic)	Chlorine atoms are removed from PCB molecule by bacteria, however, toxicity reduction is not directly correlated to dechlorination.
	Physical - Burial	Sedimentation	Impacted sediments are buried to deeper intervals which are not in the biologically active zone.
Containment	*Capping*	Conventional Sand Cap	Placement of clean sand over existing contaminated bottom to physically isolate contaminants.
		Conventional Sediment/Clay Cap	Use of dredged fine-grained sediments or commercially-obtained clay materials to achieve contaminant isolation.
		Armored Cap	Cobbles, pebbles or larger material are incorporated into the cap to prevent erosion in high-energy environments, or to prevent cap breaching by bioturbators (example: membrane gabions).
		Composite Cap	Soil, media and geotextile cap over contaminated material to inhibit contaminated pore water migration and/or inhibit bioturbators.
		Thin Layer Cap	Application of a thin (1"–3") layer of clean sediments and allowing natural resorting or bioturbation to mix the contaminated and clean sediments, which results in a surface layer of impacted material within acceptable levels.
		Enhanced Cap	Incorporation of materials such as granular activated carbon or iron filings to provide chemical binding or destruction of contaminants migrating in pore water.
	Rechannelization	Construction of New Channels	Construction of new channels to reroute surface water through non-impacted sediments or soils.
Removal	*Dredging*	Hydraulic Dredging	A rotating cutterhead loosens sediment at the suction mouth, where a centrifugal pump draws the sediment/water slurry through the pipeline. Performs efficiently in most sediments. Resuspension losses can be minimized by operational controls.
	Dry Excavation	Mechanical Dredging	A mechanical dredge consists of a barge-mounted floating crane that maneuvers a cable-suspended dredging bucket. The bucket is lowered into the sediment, and when withdrawn the cable closes the jaws of the bucket, retaining dredged material.
		Excavator	This removal option includes erecting sheet piles, or a cofferdam, around the contaminated sediments to dewater. Removal would then involve conventional excavation (backhoe) equipment.
In-situ Treatment	*Biological*	*In-situ* Slurry Biodegradation	Anaerobic, aerobic, or sequential anaerobic/aerobic degradation of organic compounds with indigenous or exogenous microorganisms. Oxygen levels, nutrients, and pH are controlled to enhance degradation. Would require sheet piling around entire area and slurry treatment would be performed using aerators and, possibly, mixers.
		In-situ Aerobic Biodegradation	Aerobic degradation of sediment *in situ* with the injection of aerobic biphenyl enrichments or other co-metabolites. Oxygen levels, nutrients, and pH are controlled to enhance degradation.

Table 6-3 Description of Potential Remedial Technologies (Continued)

GRA	Technology	Process Option	Description
In-situ Treatment (Continued)	*Biological (Continued)*	*In-situ* Anaerobic Biodegradation	Anaerobic degradation *in situ* with the injection of a methanogenic culture, anaerobic mineral medium, and routine supplements of glucose to maintain methanogenic activity. Nutrients, and pH are controlled to enhance degradation.
	Chemical	*In-situ* Slurry Oxidation	Oxidation of organics using oxidizing agents such as ozone, peroxide, or Fenton's Reagent.
		Aqua MecTool™ Oxidation	A caisson (18' × 18') is driven into the sediment and a rotary blade is used to mix sediment and add oxidizing agents such as ozone, peroxide, or Fenton's Reagent. A bladder is placed in the caisson to reduce TSS and the vapors may be collected at the surface and treated.
		In-situ Oxidation	An array of injection wells is used to introduce oxidizing agents such as ozone to degrade organics.
		Electrochemical Oxidation	Proprietary technology in which an array of single steel piles is installed and low current is applied to stimulate oxidation of organics.
	Physical-Extractive Processes	Sediment Flushing	Water or other aqueous solution is circulated through impacted sediment. An injection or infiltration process introduces the solution to the impacted area and the solution is later extracted along with dissolved contaminants. Extraction fluid must be treated and is often recycled.
		SVE/Thermally Enhanced SVE/ Bioventing	An array of extraction and injection wells is used to physically strip volatile contaminants or to stimulate biodegradation in unsaturated soil. Oxygen levels, nutrients, and pH can be controlled in bioventing applications. Removal may be enhanced by heating the system.
		Air Sparging	An array of injection wells is used to physically strip volatile contaminants or to stimulate biodegradation in unsaturated soil. Oxygen levels, nutrients, and pH can be controlled to enhance biological activity.
	Physical-Immobilization	Aqua MecTool™ Stabilization	A caisson (18' × 18') is driven into the sediment and a rotary blade is used to mix sediment and add stabilizing agents. A bladder is placed in the caisson to reduce TSS and the vapors may be collected at the surface and treated.
		Vitrification	Uses and electric current to melt soil or other earthen materials at extremely high temperatures (2,900˚–3,650 ˚F). Inorganic compounds are incorporated into the vitrified glass and crystalline mass and organic pollutants are destroyed by pyrolysis. *In-situ* applications use graphite electrodes to heat soil.
		Imbiber Beads™	A "cover blanket" of Imbiber Beads™ placed over contaminated sediments to enhance anaerobic microbial degradation processes and allow exchange of gases between sediments and surface water. The beads are spherical plastic particles that would absorb PCB vapors generated.
		Ground Freezing	An array of pipes is placed in the ground and brine at a temperature of -20˚ to -40 ˚C is circulated to freeze soil. Is only recommended for short-duration applications and to assist with excavation.
Ex-situ Treatment	*Biological*	Landfarming/ Composting	Sediment is mixed with amendments and placed on a treatment area that typically includes leachate collection. The soil and amendments are mixed using a windrow composter, conventional tilling equipment, or other means to provide aeration. Moisture, heat, nutrients, oxygen, and pH can be controlled to enhance biodegradation. Other organic amendments such as wood chips, potato waste, or alfalfa are added to composting systems.
		Biopiles	Excavated sediments are mixed with amendments and placed in aboveground enclosures. It is an aerated static pile composting process in which compost is formed into piles and aerated with blowers or vacuum pumps. Moisture, heat, nutrients, oxygen, and pH can be controlled to enhance biodegradation.

Table 6-3 Description of Potential Remedial Technologies (Continued)

GRA	Technology	Process Option	Description
Ex-situ Treatment (Continued)	*Biological (Continued)*	Fungal Biodegradation	Fungal biodegradation refers to the degradation of a wide variety of organopollutants by using their lignin-degrading or wood-rotting enzyme system (example: white rot fungus).
		Slurry-phase Biological Treatment	An aqueous slurry is created by combining sediment with water and other additives. The slurry is mixed to keep solids suspended and microorganisms in contact with the contaminants. Upon completion of the process, the slurry is dewatered and the treated sediment is removed for disposal (example: sequential anaerobic/aerobic slurry-phase bioreactors).
		Enhanced Biodegradation	Addition of nutrients (oxygen, minerals, etc.) to the sediment to improve the rate of natural biodegradation. Use of heat to break carbon-halogen bonds and to volatilize light organic compounds (example: D-Plus [Sinre/DRAT]).
	Chemical	Acid Extraction	Waste-contaminated sediment and acid extractant are mixed in an extractor, dissolving the contaminants. The extracted solution is then placed in a separator, where the contaminants and extractant are separated for treatment and further use.
		Solvent Extraction	Waste-contaminated sediment and solvent extractant are mixed in an extractor, dissolving the contaminants. The extracted solution is then placed in a separator, where the contaminants and extractant are separated for treatment and further use (example: B.E.S.T.™ and propane extraction process).
		Slurry Oxidation	The same as slurry-phase biological treatment with the exception that oxidizing agents are added to decompose organics. Oxidizing agents may include ozone, hydrogen peroxide, and Fenton's Reagent.
		Reduction/ Oxidation	Reduction/oxidation chemically converts hazardous contaminants to nonhazardous or less toxic compounds that are more stable, less mobile, and/or inert. The oxidizing agents most commonly used are hypochlorites, chlorine, and chlorine dioxide.
	Chemical/ Physical	Dehalogenation	Dehalogenation process in which sediment is screened, processed with a crusher and pug mill, and mixed with sodium bicarbonate (base catalyzed decomposition or BCD) or potassium polyethylene glycol (APEG). The mixture is heated to above 630 ˚F in a rotary reactor to decompose and volatilize contaminants. Process produces biphenyls, olefins, and sodium chloride.
		Sediment Washing	Contaminants sorbed onto fine soil particles are separated from bulk soil in an aqueous-based system on the basis of particle size. The wash water may be augmented with a basic leaching agent, surfactant, pH adjustment, or chelating agent to help remove organics and heavy metals.
		Radiolytic Dechlorination	Sediment is placed in alkaline isopropanol solution and gamma irradiated to a dose of <10 (~1% solution). Products of this dechlorination process are biphenyl, acetone, and inorganic chloride. Process must be carried out under inert atmosphere.
	Physical	Separation	Contaminated fraction of solids are concentrated through gravity, magnetic or sieving separation processes.
		Solar Detoxification	Through photochemical and thermal reactions, the ultraviolet energy in sunlight destroys contaminants.
		Solidification	The mobility of constituents in a "solid" medium are reduced through addition of immobilization additives.
	Thermal	Incineration	Temperatures greater than 1,400˚ F are used to volatilize and combust organic chemicals. Commercial incinerator designs are rotary kilns equipped with an afterburner, a quench, and an air pollution control system.

Table 6-3 Description of Potential Remedial Technologies (Continued)

GRA	Technology	Process Option	Description
Ex-situ Treatment (Continued)	*Thermal (Continued)*	High-temperature Thermal Desorption (HTTD)	Temperatures in the range of 600˚–1,200 ˚F are used to volatilize organic chemicals. These thermal units are typically equipped with an afterburner and baghouse for destruction of air emissions.
		Low-temperature Thermal Destruction	Temperatures in the range of 200˚–600 ˚F are used to volatilize and combust organic chemicals. These thermal units are typically equipped with an afterburner and baghouse for treatment of air emissions.
		Pyrolysis	Chemical Decomposition is induced in organic materials by heat in the absence of oxygen. Organic materials are transformed into gaseous components and a solid residue (coke) containing fixed carbon and ash.
		Thermal Desorption	Wastes are heated to volatilize water and organic contaminants. A carrier gas or vacuum system transports volatilized water and organics to the gas treatment system (examples: X*TRAX™, DAVES, Tacuik Process and Holoflite™ Dryer).
		Vitrification	Uses an electric current to melt soil or other earthen materials at extremely high temperatures (2.900˚–3,650 ˚F).
		High-pressure Oxidation	High temperature and pressure used to break down organic compounds. Operating temperatures Range from 150˚–600 ˚C and pressures range from 2,000–22,300 MPa (examples: wet air oxidation and supercritical water oxidation).
Disposal	*On-site Disposal*	Level-bottom Cap	Relocation of impacted sediment to discrete area and capping with a layer of clean sediments. Provides similar protection as capping, but requires substantially more sediment handling that may cause increased releases to surface water. Relocation of impacted sediment to discrete area and capping with a layer of clean sediments. Provides similar protection as capping, but requires substantially more sediment handling that may cause increased releases to surface water.
		Confined Aquatic Disposal (CAD)	Place untreated sediment within a lateral containment structure (i.e., bottom depression or subaqueous berm) and cap with clean sediment.
		Confined Disposal Facility (CDF)	Place untreated sediment in a nearshore confined disposal facility that is separated from the river by an earthen berm or other physical barrier and capped to prevent dermal contact.
		Nearshore Biofiltration Cell	Contaminated sediment is placed in a nearshore confined treatment facility (CTF) where the contents are manipulated to enhance naturally-occurring biodegradation.
		Upland Confined Fill	Place treated sediment at an on-site location. Location may require cap or other containment devices based on analytical data.
	Off-site Disposal	NR 500 WAC Landfill (county, private, industrial landfills)	Off-site disposal at a licensed commercial facility that can accept nonhazardous dewatered sediment. Depends on analytical data from dredged sediment. Dewatering required to reduce water content for transportation.
		Dedicated New Upland Landfill	A new dedicated landfill designed to contain all PCB-impacted sediments removed from the Lower Fox River.
		TSCA Subtitle C Landfill	Off-site disposal at a licensed commercial facility that can accept hazardous dewatered sediment. Depends on analytical data from dredged sediment. Dewatering required to reduce water content for transportation.
		Upland Confined Fill (commercial/-industrial)	Place treated or untreated sediment at an off-site location. Location may require cap or other containment devices based on analytical data.
		Upland Fill (residential/clean)	Place treated sediment at an off-site location. Requires that sediment be treated to a level that allows no restriction reuse.

Table 6-4 Screening of Potential Remedial Technologies - No Action, Containment, and Removal

GRA	Technology	Process Option	Initial Screening: Implementability	Initial Screening: Screening Decision	Final Screening: Effectiveness	Final Screening: Cost	Final Screening: Screening Decision
No Action	*None*	Not Applicable	Potentially applicable.	Retained	Retainment required.	Low	Retained
Institutional Controls	*Physical, Engineering, or Legislative Restrictions*	Consumption Advisories	Potentially applicable.	Retained	Provides limited protection.	Low	Retained
		Access Restrictions	Potentially applicable.	Retained	Provides limited protection.	Low	Retained
		Dredging Moratorium	Potentially applicable.	Retained	Provides limited protection.	Low	Retained
Monitored Natural Recovery	*Physical Degradation*	Desorption, Diffusion, Dilution, Volatilization	Potentially applicable.	Retained	Surface sediment concentrations are generally decreasing over time, but not at depth. PCB volatilization in Green Bay indicates degradation is occurring.	Low	Retained
	Biological - Degradation	Dechlorination (aerobic and anaerobic)	Potentially applicable.	Retained	Relatively successful for sediments with high PCB levels, but little degradation occurs at lower PCB levels.	Low	Retained
	Physical Processes	Sedimentation Burial	Potentially applicable.	Retained	Deposition and reburial is occurring, but based on bed elevation changes over time, much of the sediment is resuspended.	Low	Retained
		Resuspension and Transport	Potentially applicable.	Retained	Bed elevation changes over time indicate transport is occurring.	Low	Retained
Containment	*Capping*	Conventional Sand Cap	Easily applied *in-situ*, however, scouring must be considered. Decreased water depth may limit future uses of waterway and may impact flooding, stream bank erosion, navigation and recreation.	Retained	Isolates contaminants from the overlying water column and prevents direct contact between aquatic biota and contaminants. Effective for contaminants such as PCBs with low solubility and high sorption where the main concern is resuspension and direct contact. Modeling will be necessary to determine if a thin-layer cap will provide adequate protection of the water column from dissolved PCBs.	Low	Retained

Table 6-4 Screening of Potential Remedial Technologies - No Action, Containment, and Removal (Continued)

GRA	Technology	Process Option	Initial Screening		Final Screening		
			Implementability	Screening Decision	Effectiveness	Cost	Screening Decision
Containment (Continued)	*Capping (Continued)*	Conventional Sediment/Clay Cap	Placement of cap within the waterway may require special engineering controls. Difficult to place clay portion of a cap. Minimizes cap thickness in areas with shallow water depth.	Retained	Sediment with silt and clay is effective in limiting diffusion of contaminants. Effective for contaminants such as PCBs with low solubility and high sorption where the main concern is resuspension and direct contact. Clay caps are generally more effective than sand caps for containment of contaminants with high solubility and low sorption. These properties increase dissolution to the overlying water column and/or recontamination of sediment within the bioactive zone (upper 10 cm).	Low	Retained
		Armored Cap	Decreased water depth may limit future uses of waterway and may impact flooding, stream bank erosion, navigation and recreation.	Retained	Isolates contaminants from the overlying water column and prevents direct contact between aquatic biota and contaminants. Effective for contaminants such as PCBs with low solubility and high sorption where the main concern is resuspension and direct contact. Armoring minimizes scouring.	Low to Moderate	Retained for limited use in high-energy sections of river
		Composite Cap (geotextile)	Decreased water depth may limit future uses of waterway and may impact flooding, stream bank erosion, navigation and recreation.	Retained	Isolates contaminants from the overlying water column and prevents direct contact between aquatic biota and contaminants. Use of geotextiles may not be necessary for contaminants such as PCBs with low solubility and high sorption where the main concern is resuspension and direct contact.	Low to Moderate	Retained
		Thin-layer Cap	Minimizes reduction in water depth that may limit future use of river and may impact flooding, stream bank erosion, navigation, and recreation.	Retained	Effective for contaminants that are amenable to natural attenuation. PCBs are not amenable to natural attenuation.	Low	Eliminated

Table 6-4 Screening of Potential Remedial Technologies - No Action, Containment, and Removal (Continued)

GRA	Technology	Process Option	Initial Screening: Implementability	Initial Screening: Screening Decision	Final Screening: Effectiveness	Final Screening: Cost	Final Screening: Screening Decision
Containment (Continued)	*Capping (Continued)*	Enhanced Cap	Decreased water depth may limit future uses of waterway and may impact flooding, stream bank erosion, navigation and recreation.	Retained	Provides similar direct contact protection as sand cap, but additives are designed to increase retention time in the cap or treat pore water. Additives used for the purpose of increasing retention time and treating pore water would have little effect on PCBs with low solubility and high sorption.	Low to Moderate	Eliminated
Containment (Continued)	*Rechan-nelization*	Construction of New Channels	Rerouting channels is often not feasible for the Lower Fox River.	Eliminated			
Removal	*Dredging*	Hydraulic Dredging	Produces low slurry density and results in high water treatment costs. Limited ability to remove debris.	Retained	Can effectively dredge all types of materials. Superior in minimizing sediment resuspension compared to other dredges. Low slurry density.	Low	Retained
Removal	*Dredging*	Mechanical Dredging	Readily available in the U.S. Vessel draft precludes operations in water with depths less than 6'. May be difficult to implement upstream of the De Pere dam due to barge access/construction issues.	Retained	Can be operated to produce low suspended solids in the water column, thereby reducing water quality impacts. Level cut and low suspended solids also provide less opportunity for recontamination of dredged areas.	Low	Retained
Removal	*Dry Excavation*	Excavator	An enclosed and drained berm or sheet pile wall would need to be constructed to be water-impervious and water needs to be removed or diverted. Difficult to implement in deeper water or areas with bedrock.	Retained	Sheet pile isolates contaminated area during removal activities to minimize contamination of nearby sediments and water.	Moderate to High	Retained

Table 6-5 Screening of Potential Remedial Technologies - Treatment

GRA	Technology	Process Option	Initial Screening		Final Screening		
			Implementability	Screening Decision	Effectiveness	Cost	Screening Decision
***In-situ* Treatment**	*Biological*	*In-situ* Slurry Biodegradation	Requires in-water steel piling around treatment area and extensive water quality monitoring outside piles. Biodegradation has not been demonstrated to effectively remediate PCBs. No known full-scale applications.	Eliminated			
		In-situ Aerobic Biodegradation	Work performed to date has only been performed in the laboratory. Some contaminants (e.g., PCBs) generally not amenable to aerobic degradation. Has not been effective for PCBs in field demonstrations.	Eliminated			
		In-situ Anaerobic Biodegradation	Work performed to date has only been performed in the laboratory. Laboratory testing data has indicated only minor removal is achievable. Has not been effective for PCBs in field demonstrations.	Eliminated			
	Chemical	*In-situ* Slurry Oxidation	Requires in-water steel piling around treatment area and extensive water quality monitoring outside piles. No known full-scale applications.	Eliminated			
		Aqua MecTool™ Oxidation	May have difficulty injecting high air flows into caisson with standing water while preventing generation of TSS. No known completed full- or pilot-scale projects.	Eliminated			
		In-situ Oxidation	Requires in-water steel piling around treatment area and extensive water quality monitoring outside piles. No known full-scale applications.	Eliminated			
		Electrochemical Oxidation	Applicability for use in water is not known. No demonstrated sediment application.	Eliminated			
	Physical-Extractive Processes	Sediment Flushing	Requires in-water steel piling around treatment area and extensive water quality monitoring outside piles. No known full-scale applications.	Eliminated			
		SVE/Thermally Enhanced SVE/ Bioventing	Technology is applicable to vadose zone soil or dewatered soil.	Eliminated			

Table 6-5 Screening of Potential Remedial Technologies - Treatment (Continued)

GRA	Technology	Process Option	Initial Screening: Implementability	Initial Screening: Screening Decision	Final Screening: Effectiveness	Final Screening: Cost	Final Screening: Screening Decision
***In-situ* Treatment (Continued)**	*Physical-Extractive Processes (Continued)*	Air Sparging	Requires in-water steel piling around treatment area and extensive water quality monitoring outside piles. Possible generation of exceedances through leakage from sheet pile. Targets VOCs and other readily degradable organics rather than PCBs. No known sediment applications.	Eliminated			
	Physical-Immobilization	Aqua MecTool™ Stabilization	Proprietary technology that has been used in a pilot-scale application in Wisconsin with coal tar-contaminated sediments. Previous trials with this technology created water treatment problems inside the caisson.	Eliminated			
		Vitrification	Requires less than 60% water content. Remaining sediment surface may not provide suitable habitat. No known sediment applications.	Eliminated			
		Imbiber Beads™	Not well demonstrated for remediation of bottom sediments. Removal and disposal of the blanket is not well demonstrated.	Eliminated			
		Ground Freezing	Application in presence of standing water has not been tested. Standing water likely provides a significant sink for cold temperatures and would substantially increase cost.	Eliminated			
***Ex-situ* Treatment**	*Biological*	Landfarming/ Composting	Requires a large amount of space. Contaminants generally not amenable to aerobic degradation. Inorganic contaminants will not be degraded.	Eliminated			
		Biopiles	Requires large upland area. Used for reducing concentrations of petroleum constituents in soils. Applied to treatment of nonhalogenated VOCs and fuel hydrocarbons. Contaminants generally not amenable to aerobic degradation.	Eliminated			

Table 6-5 Screening of Potential Remedial Technologies - Treatment (Continued)

GRA	Technology	Process Option	Initial Screening		Final Screening		
			Implementability	Screening Decision	Effectiveness	Cost	Screening Decision
Ex-situ Treatment (Continued)	Biological (Continued)	Fungal Biodegradation	No known full-scale applications. High concentrations of contaminants may inhibit growth. The technology has been tested only at bench scale.	Eliminated			
		Slurry-phase Biological Treatment	Large volume of tankage required. No known full-scale applications. Contaminants generally not amenable to biodegradation. Inorganic constituents will not be degraded.	Eliminated			
		Enhanced Biodegradation	Not available on a commercial scale. PCB not amenable to biodegradation. Inorganic constituents will not be degraded.	Eliminated			
	Chemical	Acid Extraction	Commercial-scale units are in operation. Suitable for sediments contaminated with heavy metals. Not applicable to PCB-impacted sediment.	Eliminated			
		Solvent Extraction	At least one commercial unit available. Effective for treating sediments containing PCBs. Extraction of organically-bound metals and organic contaminants creating residuals with special handling requirements. The process is sensitive to sediment characteristics (i.e., clay content, pH). PCBs are not destroyed and may require further treatment by another technology.	Eliminated			
		Slurry Oxidation	Large volume of tankage required. No known full-scale applications. High organic carbon content in sediment will increase volume of reagent and cost.	Eliminated			
		Reduction/ Oxidation	Target contaminant group for chemical redox is inorganics. Less effective against nonhalogenated VOCs, SVOCs, fuel hydrocarbons, and pesticides. Not cost-effective for high contaminant concentrations because of large amounts of oxidizing agent required.	Eliminated			

Table 6-5 Screening of Potential Remedial Technologies - Treatment (Continued)

GRA	Technology	Process Option	Initial Screening		Final Screening		
			Implementability	**Screening Decision**	**Effectiveness**	**Cost**	**Screening Decision**
***Ex-situ* Treatment (Continued)**	*Chemical/ Physical*	Dehalogenation	Generates secondary waste streams of air, water, and sludge. Similar to thermal desorption, but more expensive. Solids content above 80% is preferred. Technology is generally not cost-effective for large volumes.	Retained	Effective for treating sediments containing PCBs. The presence of metals may affect performance. High moisture content adversely effects treatment. The process is sensitive to sediment characteristics (i.e., clay content, pH). The APEG process often needs to cycle numerous times to achieve the desired results and may cause the formation of dioxins and furans.	Moderate	Eliminated
		Sediment Washing/ Fractionation	Not an easily-accessible commercial process (limited use in the United States). Process has difficulty with fine-grained sediment. Not effective for PCBs.	Eliminated			
		Radiolytic Dechlorination	Only bench-scale testing has been performed. Difficult and expensive to create inert atmosphere for full-scale project.	Eliminated			
	Physical	Separation	Not effective on fine-grained sediment and in presence of high moisture content. Target compounds are SVOCs, fuels, and inorganics. Previous tests on Fox River sediments have shown no benefit in reducing contaminated sediment volumes, but it has been demonstrated as effective in improving the efficiencies of the dewatering process.	Retained	Effective for dewatering dredged material. Recent PCB mass balance studies conducted on Deposit N Fox River sediments have shown 96% of PCB mass is contained in filter cake after dewatering.	Moderate	Retained
		Solar Detoxification	The process has been successfully demonstrated at pilot scale. The target contaminant group is VOCs, SVOCs, solvents, pesticides, and dyes. Some heavy metals may be removed. Only effective during daytime with normal intensity of sunlight.	Eliminated			

Table 6-5 Screening of Potential Remedial Technologies - Treatment (Continued)

GRA	Technology	Process Option	Initial Screening: Implementability	Initial Screening: Screening Decision	Final Screening: Effectiveness	Final Screening: Cost	Final Screening: Screening Decision
***Ex-situ* Treatment (Continued)**	*Physical*	Solidification	Bench-scale studies have added immobilizing reagents ranging from Portland cement to lime cement, kiln dust, pozzolan, and proprietary agents with varying success. Dependent on sediment characteristics and water content.	Retained	Lime was successfully added to dewatered dredged material from the Lower Fox River demonstration projects. Considered for use during the dewatering operation to remove excess water and prepare material for disposal.	Moderate	Retained
	Thermal	Incineration	Only one off-site fixed facility incinerator is permitted to burn PCBs and dioxins. Mobile incinerators are available for movement to a fixed location in close proximity to the contaminated sediments. May require an acid gas scrubber for treatment of air emissions.	Retained	High temperatures result in generally complete decomposition of PCBs and other organic chemicals. Effective across wide range of sediment characteristics. At a minimum, consider use for TSCA-level sediments.	Very High	Retained as high-cost alternative
		High-temperature Thermal Desorption (HTTD) then Destruction	Technology readily available as mobile units which would need to be set up at a fixed location in close proximity to the contaminated sediments.	Retained	Thermal desorption and combustion is effective with a range of SVOCs. Target contaminants for HTTD are SVOCs, PAHs, PCBs and pesticides. Destruction of organic compounds occurs within an off-gas chamber or unit that is integrated into the thermal desorption system.	High	Retained
		Low-temperature Thermal Desorption	Technology readily available as mobile units which would need to be set up at a fixed location in close proximity to the contaminated sediments. Thermal desorption and combustion is effective with a range of SVOCs. Typically not employed with chlorinated compounds or VOCs.	Eliminated			
		Pyrolysis	High moisture content increases treatment cost. Generates air and coke waste streams. Target contaminant groups are SVOCs and pesticides. It is not effective in either destroying or physically separating inorganics from the contaminated medium. Limited performance data are available for pyrolytic systems treating hazardous wastes containing PCBs, dioxins, and other organics.	Eliminated			

Table 6-5 Screening of Potential Remedial Technologies - Treatment (Continued)

GRA	Technology	Process Option	Initial Screening		Final Screening		
			Implementability	Screening Decision	Effectiveness	Cost	Screening Decision
***Ex-situ* Treatment (Continued)**	*Thermal (Continued)*	Thermal Desorption	Fine-grained sediment and high moisture content will increase retention times. Widely-available commercial technology for both on-site and off-site applications. Acid scrubber will be added to treat off-gas.	Retained	Demonstrated effectiveness at several other sediment remediation sites. Vaporized organic contaminants that are captured and condensed need to be destroyed by another technology. The resulting water stream from the condensation process may require further treatment as well.	Low	Retained
		Vitrification	Requires less than 60% water content. Thermally treats PCBs and stabilizes metals, but at a much higher cost.	Retained	Destroys PCBs and immobilizes metals. Fundamentally, the process thermally treats PCBs and stabilizes metals. High moisture content adversely effects the treatment. Residuals are produced that must be treated and/or disposed. Recent pilot studies on Fox River sediments have shown that the process can be effective. Volume reduction to glass pellets is approximately 10:1.	High	Retained
		High-pressure Oxidation	Predominantly for aqueous-phase contaminants. Wet air oxidation is a commercially-proven technology for municipal wastewater sludges and destruction of PCBs is poor. Supercritical water oxidation has demonstrated success for PCB destruction in bench- and pilot-scale testing.	Eliminated			

Table 6-6 Screening of Potential Remedial Technologies - Disposal

GRA	Technology	Process Option	Initial Screening		Final Screening		
			Implementability	Screening Decision	Effectiveness	Cost	Screening Decision
Disposal	*On-site Disposal*	Level-bottom Cap	Decreased water depth may limit future use of river and may impact flooding, stream bank erosion, navigation, and recreation.	Retained	Isolates contaminants from the overlying water column and prevents direct contact between aquatic biota and contaminants. Effective for contaminants such as PCBs with low solubility and high sorption where the main concern is resuspension and direct contact. Releases from impacted sediment may occur during consolidation.	Moderate	Retained
		Confined Aquatic Disposal (CAD)	CAD may not be implemented due to ban on open-water disposal in the Great Lakes, but carried forward in FS as feasible for Green Bay.	Retained	CAD sites have been successfully constructed in many urban bays. Effective for isolating contaminants such as PCBs.	Moderate	Retained
		Confined Disposal Facility (CDF)	Portion of river to be used must be expendable. Potential impacts on flooding, stream bank erosion, navigation, and recreation. Requires USACE 404 permit.	Retained	Risk of discharge to river or bay through outer berm or containment wall.	Moderate	Retained
		Nearshore Biofiltration Cell	Portion of river to be used must be expendable. Potential impacts on flooding, stream bank erosion, navigation, and recreation. Requires USACE 404 permit. Engineering design of a full-scale system may be difficult to implement due to the potential need for oxygen additions. Demonstration project on Sheboygan River sediments resulted in incomplete degradation of PCBs and concerns about full-scale engineering design.	Eliminated			
		Upland Confined Fill	Standard construction techniques. Requires available upland space.	Retained	Standard construction techniques. Requires available upland space. Long-term successful storage.	Moderate	Retained

Table 6-6 Screening of Potential Remedial Technologies - Disposal (Continued)

GRA	Technology	Process Option	Initial Screening: Implementability	Initial Screening: Screening Decision	Final Screening: Effectiveness	Final Screening: Cost	Final Screening: Screening Decision
Disposal (Continued)	*Off-site Disposal*	NR 500 WAC Landfill (county, private, industrial landfills)	Sediment must pass strength test and be able to support slopes for disposal, especially with large quantities. WDNR has authority to dispose of PCB sediment in NR 500 WAC facilities (re-approval pending).	Retained	EPA waiver allows WDNR to regulate disposal of PCB-contaminated sediments in NR 500 WAC landfills; however, TSCA sediments must pass paint filter test for transport and disposal. Some non-municipal landfills may require upgrades to meet NR 500 criteria.	Low to Moderate	Retained
		Dedicated New Upland Landfill	Construction requirements for a dedicated landfill would generally be the same as the construction requirements for a municipal landfill. Time required to site, design and construct the landfill is a consideration. If dredge slurry is pumped long distances directly to landfill, engineering and community concerns need to be addressed.	Retained	EPA waiver allows WDNR to regulate disposal of PCB-contaminated sediments in NR 500 WAC landfills. The dedicated landfill could be centrally located in an area to allow access from all areas of the river.	Moderate to High	Retained
		TSCA Subtitle C Landfill	Sediment must pass paint filter test for transport and disposal sediment must also pass strength test and be able to support slopes for disposal, especially with large quantities. WDNR has authority to dispose of PCB sediment in NR 500 WAC facilities.	Retained	Commercial permitted landfill.	High	Retained
		Upland Confined Fill (commercial/-industrial)	Standard construction techniques. Treatment to Wisconsin commercial/industrial criteria.	Retained	Sediments must be treated to commercial/industrial criteria. May require liner and cap depending on constituent concentrations.	Low to Moderate	Eliminated
		Upland Fill (residential/clean)	Standard construction techniques. Treatment to Wisconsin clean fill criteria.	Retained	Sediment must meet residential fill criteria.	Low	Retained

Table 6-7 Ancillary Technologies

Technology	Process Option	Description	Implementability and Effectiveness	Cost	Screening Decision
Passive Dewatering	On-barge	Mechanically-dredged sediments are placed within a barge which either allows excess water to flow into river, or to accumulate in an on-board sump where it is removed and treated.	Water drained from sediment on barge into river may not meet NPDES discharge standards. Gravity-drained water may contain high concentrations of TSS. Not all river segments may be accessible to a barge. Sediments could require additional treatment to pass paint filter test.	Low	Retained
	Dewatering Lagoons/Ponds	Dredged sediments are placed within constructed lagoons where sediments are allowed to gravity settle.	Construction of ponds near river may involve removal of wooded areas. Construction costs may involve contingencies to address potential spills and leaks. Effluent water may contain high concentrations of TSS. Average annual rainfall and evaporation approximately equal. Retention time affects production rates. Based on Fox River design estimates, dewatered sediments would likely require solidification to pass paint filter test.	Low to Moderate	Retained
	Solidification	Dredged sediments are mixed with amendments (e.g., Portland cement, lime, and/or fly ash mixture) to produce a product which passes regulatory requirements (e.g., paint filter test).	Staging, mixing, and curing areas required. Solidified sediments have increased mass of unsolidified sediments. Most effective on partially-dewatered/high-solid sediments.	Moderate	Retained
Mechanical Dewatering	Centrifugation	Rapidly rotates fluid mixture to separate the components based upon mass. Flocculents are often used to increase effectiveness.	Production rate is based on size and quantity of centrifuges used to dewater. Typical production rate of a single centrifuge is 20–500 gpm. Due to handling issues, more effective on dredge spoils containing a low percent of solids.	Moderate	Retained
	Belt Press	Uses belts that compress sediments against rollers to achieve high-pressure compression and shear to remove water from dredged sediments.	Production rate is based on the size and quantity of belt presses used. Typical production rate of a single belt press is 40–100 gpm. Sediments are initially gravity-drained which could produce high concentration of TSS. PCB mass balance studies conducted on Fox River sediments have shown 96% of mass is retained in dewatered filter cake.	Moderate to High	Retained
	Hydrocyclone	Continuous operating cone-shaped device which uses centrifugal force to accelerate settling.	Production rate and minimum separation size depended upon size of hydrocyclone (larger capacity provides a larger minimum separation size). Typical production rate of a single hydrocyclone is 50–3,500 gpm.	Moderate	Retained
	Diaphragm Filter Press	Dewaters dredged sediments by passing slurry through a vertical filter. Uses inflatable diaphragms to increase pressures on sediments prior to removing sediments from filter.	Production rate is based on the size and quantity of filter presses used. Typical production rate of a single filter press is 1,200–6,000 gpm. Due to nature of operation, does not allow for continuous operation.	Moderate to High	Retained

Table 6-7 Ancillary Technologies (Continued)

Technology	Process Option	Description	Implementability and Effectiveness	Cost	Screening Decision
Wastewater Treatment (for mechanical dredging)	Sedimentation	Passive physical separation in a dewatering cell to remove solids.	Basic form of primary treatment used at wastewater treatment facilities. Gravity settling is used the most extensively.	Low	Retained
	Filtration	Water is fed through sand or mixed-media filter for solids retention. Gravity or pressure pumped.	Filtration media is commonly used in CDFs. Most organic compounds, especially hydrophobic ones, are generally removed with the solids.	Low	Retained
	Coagulation Aid, Flocculation and Settling	Coagulant aid added to slurry stream then flowed through clarifiers for thickening.	Coagulant and polymer flocculents used in pilot projects to promote removal of silty clay. Limited full-scale application.	Low to Moderate	Eliminated
	Adsorption Carbon Filter	Uses activated granular carbon.	Useful for removing organic substances. Spent carbon must be frequently discarded and disposed of. The Fox River demonstration projects met effluent water quality criteria without the use of carbon filters, however, carbon use should be considered.	Low to Moderate	Eliminated (but possibly add later)
	Oxidation	Oxidation of organic molecules to carbon dioxide and water by chemical or ultraviolet oxidation.	Technology is effective for removing organic compounds including PCBs.	High	Eliminated
	Mechanical	Discussed under Dewatering Process Options.			
Solid Residuals Management	Sediment	Discussed under Disposal Technologies.			
	Water	Discussed above and returned to site or transported to POTW for treatment and disposal.			
	Air Emissions	Treated on site and discharged at generation site.			
	Other Solids (i.e., PPE)	To local municipal landfill.			

Table 6-7 Ancillary Technologies (Continued)

Technology	Process Option	Description	Implementability and Effectiveness	Cost	Screening Decision
Transportation	Truck	After dewatering, stockpiled solids placed in sealed trucks by backhoes.	Portable and flexible. Readily available.	High	Retained
	Rail	Sediment placed in railcars for hauling long distances.	Limited availability. Difficult loading/unloading logistics.	High	Eliminated
	Barge	High-solids dredged material mechanically placed in barge. After dewatering, offloaded using backhoe and trucks.	Used with mechanical dredging operations. Consider dewatering limitations on barge.	Moderate	Retained
	Pipeline	Transports dredged material in slurry form directly to disposal site or treatment site if necessary.	Preferred for hydraulic dredging and transport over short distances (<3 km). Booster pumps need consideration. Must be hydraulically linked. A 20-mile-long slurry pipe run was successfully implemented over 1 year in White Rock Lake, Texas. Requires sufficient land space near dredging operations to serve as slurry transfer station between the dredge and pipeline.	Moderate	Retained
Water Quality	Containment Structures	Placement of physical barriers (silt screens, curtains, sheet pile walls) to lower TSS transport.	Mixed effectiveness. Highly dependent on site conditions.	Moderate	Retained (but not costed)
	Operator Modifications	Use slower dredging rates and speeds.	Effective, but requires monitoring. Selection of a qualified dredge operator may have the largest influence on dredge or cap implementation.	Low	Retained

Table 6-8 Deposit N Demonstration Project Summary

Parameter	Specification
Dredge Equipment	Hydraulic round cutterhead (Moray/Ultra) Rotating, variable speed 8" pump and 8" double-walled pipeline (single in 1999)
Dredge Period	November 26 to December 31, 1998 August 20 to October 14, 1999 (104 days)
Production Rate	80 cubic yards per day (average)
Hours of Operation	Treatment: 24 hours/day in 1998; 7 days/week, 10 hours/day in 1999
Area	3 acres
Water Depth	8' (average)
Volume/Mass	8,175 cy (112 pounds PCBs)
Percent Solids	0.4%–6% (average is 2%) dredge slurry
Dewatering Method	⅜" shaker screen to 12,000-gallon V-bottom tank Augered to 2- hydrocyclones, to 4 - 20,000-gallon mixing tanks, to 2 - 200-cf filter presses, then stockpiled
Water Treatment	Bag filters, sand filters, and liquid-phase carbon adsorbers
Disposal	Wayne Disposal Landfill (TSCA material) Winnebago County Landfill (non-TSCA material)
Environmental Controls	Perimeter turbidity barriers (80-mil HDPE) Silt curtain Deflection barrier (80-mil HDPE) Real-time in-river water quality monitoring
WPDES Effluent Limits	Mercury: 1.7 μg/L daily maximum, 0.0013 pounds/day weekly average PCBs: 1.2 μg/L daily maximum, 0.0036 pounds/day monthly average
Monitoring	Daily water quality, air, diver-collected surface sediment, mass balance study, hourly and daily flow rates compiled from USGS
Limitations	Coal and large boulders resting on river bed nearshore—this area not dredged. Additional dredging in west lobe (3" to bedrock) produced very low percent slurry solids.
Removal Goals	Dredge sediment to within 3 inches and 6 inches of bedrock Conduct verification sampling of residuals Also removed sediment from Deposit O
Dredge Costs	$20.73 per cy dredged
Total Costs	$3.9 million ($540 per cy)

Table 6-9 SMU 56/57 Demonstration Project Summary

Year 1999 Parameter	Year 1999 Specification
Dredge Equipment	Hydraulic round cutterhead—used only a few days Hydraulic horizontal auger (IMS 5012 Versi dredge) 9' 12" pump and 12" single- and double-walled pipeline
Dredge Period	September 10 to December 12, 1999 (96 of 108 days)
Production Rate	60 cy/hr (average) 294 cy/day (average) Goal: 200 cy/hr and 900 cy/day
Hours of Operation	Treatment: 24 hours/day and 7 days/week Dredge: 4.3 hours/day (average)
Area	NA
Water Depth	2' nearshore to 14' mid-channel
Volume/Mass	31,346 cy (1,326 pounds PCBs)
Percent Solids	4.4% (average) in dredge slurry Goal: 7.5%
Dewatering Method	Passive dewatered in equalization basins, Horizontal augered/piped to shaker screens, to 7 - 20,000-gallon mixing feed tanks, to 4 - 100-cf and 2 - 200-cf filter presses, then stockpiled
Water Treatment	Equalization basin, sand/gravel filters, granular activated carbon (GAC) filter - 75,256,500 gallons treated Peak capacity 1,100 gpm $0.26/gallon or $64/cy of sediment
Disposal	On-site industrial landfill at Fort James Corp. 26,927 wet tons (11,696 dry tons) $68/cy
Environmental Controls	Anchored silt curtain (8" closed cell foam wrapped in PVC-coated fabric) in adjoining panels
WPDES Effluent Limits	Mercury: 1.7 μg/L daily maximum, 0.0026 pounds/day weekly average PCBs: 1.2 μg/L daily maximum, 0.0072 pounds/day weekly average
Monitoring	Daily water quality, real-time turbidity, pre- and post-sediment cores, dewatered sediment, dredge slurry, and effluent testing (mass balance study), daily flow rates compiled from USGS
Limitations	Lower percent solids than predicted
Removal Goals	Remove all material within dredge prism to a design elevation of 565' Collect verification samples of surface residuals (only 1 of 19 subunits achieved target depth)
Dredge Costs	$27/cy dredged
Total Costs	$8.97 million ($286 per cy)

Note:

NA - Not available.

Table 6-9 SMU 56/57 Demonstration Project Summary (Continued)

Year 2000 Parameter	Year 2000 Specification
Target Goal	Remove 50,000 cy of sediment, assuming that remaining sediments have <1 ppm PCBs.
Dredge Equipment	3 hydraulic horizontal augers with submersible pumps
Dredge Period	August 23 to November 8, 2000
Production Rate	833 cy/day (average)
Hours of Operation	Treatment: 24 hours/day and 7 days/week Dredge: 24 hours/day and 7 days/week
Area	NA
Water Depth	Same in 1999/2000
Volume/Mass	50,316 cy (670 pounds PCBs; total PCBs removed 2,111 pounds)
Percent Solids	8.4% (average) in dredge slurry
Dewatering Method	Dredge slurry piped to a booster pump, then pumped to land-based facility through to vibrating shaker screens on V-bottom tank, to hydrocyclones, to a 20,000-gallon agitated pump tank, to plate-and-frame mechanical presses (2 - 200 cf)
Water Treatment	Water surge tank, cloth bag filters, sand filters, carbon absorption system, cloth bag filters 66,329,000 gallons treated
Disposal	Trucked to on-site industrial landfill at Fort James Corp. Cell 12A (6 miles away) 51,613 dry tons with 59% solids (average)
Environmental Controls	Anchored silt curtains around perimeter additional silt curtains to separate dredge areas and avoid recontamination
WPDES Effluent Limits	Mercury: 1.7 μg/L daily maximum, 0.0026 pounds/day weekly average PCBs: 1.2 μg/L daily maximum, 0.0072 pounds/day weekly average
Monitoring	Every other day water quality, real-time turbidity, pre- and post-sediment cores, filter cake, dredge slurry, effluent testing, daily flow rates compiled from USGS
Limitations	Dredge area covered with 8" sand cap (required for surface sediments between 1 and 10 ppm PCBs) after one cleanup pass to ensure protection before onset of winter Added larger filter presses and one additional dredge (total 3) to increase production rates
Removal Goals	Remove 50,000 cy of sediment within dredge prism Collect verification samples of surface residuals
Dredge Costs	NA
Total Costs	Actual dredge and on-site disposal cost $8.18 million ($159 per cy) value Cost for management and value of on-site Cell 12A ($296 per cy)

Note:

NA - Not available.

Table 6-10 Summary of Selected Wisconsin Landfills Within Approximately 40 Miles of the Lower Fox River

Facility Name	No.[4]	County	Status		Remaining Capacity [3] (cubic yards)	Notes
			Existing Landfill	Proposed Landfill		
Municipal [1]						
Brown County East	1	Brown	✓		934,875	
Brown County South	2	Brown		✓	8,025,000	b
Superior Services - Hickory Meadows	3	Calumet		✓	7,500,000	
Kewaunee County Southwest	4	Kewaunee	✓		259,367	d
Mar-Oco	5	Marinette	✓		1,080,754	
Outagamie County Southwest Division	6	Outagamie	✓		5,600,000–6,600,000	a
Shawano County Phase 2	7	Shawano	✓		716,500	a
W M W I - Ridgeview Recycling	8	Manitowoc	✓		4,770,000	a
W M W I - Valley Trail	9	Green Lake	✓		4,905,300	a
Winnebago County - Sunnyview	10	Winnebago	✓		5,015,557	
Non-Municipal [2]						
Appleton Papers, Inc. Tn of Harrison	11	Calumet	✓		unknown	
Appleton Papers, Inc. - Locks MI	12	Outagamie	✓		65,800	c
Fort James Corp. - Green Bay West	13	Brown	✓		3,972,984	
Wisconsin Tissue Mills North	14	Winnebago	✓		312,569	

Notes:

[1] Landfill is operated for the disposal of municipal solid waste and some industrial waste. May be either publicly or privately owned.

[2] Landfill is operated for the disposal of industrial waste and is privately owned.

[3] Remaining capacity as of January 1998 and proposed capacity.

[4] Landfill identification for Figure 6-7, Lower Fox River Feasibility Study.

a. Proposed or existing facilities which are expansions to an existing facility.

b. A 3,700,000-cubic-yard monofill was approved as part of this site's Feasibility Study, but this monofill is not proposed or being developed at this time.

c. Not an NR 500-approved facility; landfill modifications required prior to the acceptance of sediments.

d. Facility is a balefill; landfill modifications required prior to the acceptance of sediments.

Table 6-11 Sediment Melter Demonstration Project Summary

Parameter	Specification
Target Goal	Evaluate the feasibility of a vitrification technology based on standard glass furnace technology to treat contaminated Lower Fox River sediments.
Pilot Melter Equipment	Refractory lined rectangular melter measuring 10 square feet.
Vitrification Period	June 16–23, 2001 and August 11–18, 2001 on a 24-hour/day time frame.
Dryer Equipment	Bench-scale Holoflite® dryer. Drying analysis performed at Hazen Research, Inc., Golden, Colorado.
Sediments Volume	60 tons of dredged and dewatered sediments from Lower Fox River.
Percent Solids	50% by weight.
Dryer Efficiency	Dryer equipment dried sediments to 10% moisture.
Metal Separation	13 bar magnets used to recover significant amounts of magnetic material.
Flux Material	5% sodium sulfate by weight.
Melter Temperature	Ranged between 2,600 and 2,900 °F.
Percent Moisture (feed sediments)	Ranged between 5% and 20%.
Pilot Melter Processing Rate	2 tons/day or 170 pounds of river sediment/hour.
Environmental Controls	Air quality control equipment for treating air emissions.
Removal Efficiency	Dioxins and furans are not generated during the treatment process.
Limitations	Moisture content of river sediment affect feed rates and material handling. Moisture content greater than 20% tended to bridge in the charger and cake around the auger of the melter. Downstream end of the pilot melter system experienced plugging due to accumulation of particulates and sulfates, primarily due to use of sodium sulfate as flux.
Glass Aggregate Testing	Performed ASTM water leach test and SPLP test. The tests did not detect any dioxins, furans, PCB congeners, SVOCs, or any of the eight heavy metals in the glass aggregate.
Total Costs	Not applicable. Unit costs were developed for full-scale melter facilities. Unit cost analysis for full-scale melter units are presented in Appendix G.